WASTEWATER TREATMENT SLUDGE AND SEPTAGE MANAGEMENT IN VERMONT

Vermont Department of Environmental Conservation
Waste Management & Prevention Division
Residual Waste & Emerging Contaminants Program

Ernie Kelley and Eamon Twohig
September 2016

WASTEWATER TREATMENT SLUDGE
AND SEPTAGE MANAGEMENT IN VERMONT
September 2016

Table of Contents & List of Tables

Introduction **3**
Residual Waste and Biosolids **3**
Current Biosolids Management: U.S., New England and Vermont **5**
Figure 1. Location of Vermont's biosolids and septage management facilities 5
Table 1. Sludge disposal option percentages (%) and dry weights by New England states in 2011. 6
Biosolids Regulation: Federal and Vermont **8**
Table 2. Exposure Pathways used in Land Application Risk Assessment. 10
Table 3. Comparison of Federal and Vermont pollutant concentration (mg/kg, dry wt.) standards for land application of biosolids. 13
Table 4. Vermont Cumulative Pollutant Loading Rate Limits (kg/ha). * 15
Table 5. Comparison of Vermont and Federal monitoring requirements for land application sites. 16
Table 6. Comparison of Vermont and Federal minimum required isolation distance (in feet) requirements. 16
Current Permitting Requirements **20**
Innovative Toilet Technology **21**
Emerging Contaminants in Biosolids **23**
Table 7. RSC values and maximum observed concentrations of target PPCPs in biosolids 25
Transport and Fate of Biosolids Bourn CECs in the Environment **28**
Table 8. Literature review of recent studies of plant uptake of emerging contaminants. 30
Table 9. Half-life (days) of selected organic compounds in biosolids amended soil systems. 33
Emerging Concerns for Pathogens **37**
Reported Adverse Impacts on Human and Animal Health **39**
Table 10. Ruane Farm: Loading rates (dry tons/acre). 43
Table 11. Ruane Farm: Annual application rates (dry tons/acre). 44
Table 12. Ruane Farm: post-application cadmium (Cd) and lead (Pb) soil concentrations (mg/kg, dry wt.). 46
Table 13. Ruane Farm: Concentrations (mg/L) of lead (Pb) and cadmium (Cd) in groundwater. 46
Septage **47**
Table 14. Average metals concentrations (mg/kg, dry wt.) and solids percentage (%) in septage. 48
Table 15. Comparison of typical permitted loading rate for various septage management options 49
Economics **50**
Table 16. Comparative cost ($US) of sewage sludge disposal options (per wet ton). 50
Table 17. Sludge management options, benefit, and cost per wet ton in Vermont 52
Management Alternatives **52**
References **55**
Appendix 1: Description of Highly Exposed Individuals (HEIs) **64**
Appendix 3: 2015 biosolids management statistics **79**
Appendix 4: 2015 septage management statistics **80**
Appendix 5: Radionuclides **81**
Appendix 6: Dioxin/PCB toxicity factors **82**
Appendix 7: State biosolids contaminant limits **83**
Appendix 8: International biosolids contaminant limits **86**
Appendix 9: Acronyms **87**

WASTEWATER TREATMENT SLUDGE
AND SEPTAGE MANAGEMENT IN VERMONT
September 2016

Introduction

On November 5, 2013, the Residuals Management Section of the Watershed Management Division in the Vermont Department of Environmental Conservation (DEC) [now located in the Residual Waste & Emerging Contaminants Program (Program) in the Waste Management & Prevention Division] hosted a public forum on the topic of biosolids management. Various stakeholders and citizens, representing a range of viewpoints, attended the forum to make presentations, provide testimony, voice concerns and ask questions. The forum represented DEC's first step toward developing a new set of regulations governing the management of residual wastes. The purpose of this white paper is to present a broad overview of the current state of sludge and septage management in Vermont and provide a general survey of scientific research applicable to concerns and issues raised at the forum.

This paper is not intended to establish policy or regulation or to promote one means of residuals management over another. Rather, the intent of this paper is to present an unbiased base of information upon which those decisions can ultimately be made. To the greatest extent feasible, the authors of this paper have attempted to present information in a manner that the general public can grasp; and, for those who desire to dig a bit deeper, by providing references to the information cited herein through the use of hyperlinks embedded within the text of the document and in the references section. The studies and references cited represent only a fraction of the research that has been conducted on these issues. As with any subject of scientific research on controversial topics, there is an ample body of literature purporting to support both sides of the issues. This paper attempts to present an unbiased report of both the strengths and weaknesses of that science. To the greatest extent practical, only peer reviewed literature has been cited; although several important non-peer reviewed journal articles are referenced. Where differences in experimental methodology investigating the same question result in significantly different conclusions, we have attempted to provide citations representing both sides. However, land application is inarguably the most controversial of the currently employed management practices, hence a major focus of this paper is on the science and regulations underlying that practice.

Ernie Kelley, Program Manager, VT-DEC Residual Waste & Emerging Contaminants Program
Eamon Twohig, Environmental Analyst V, VT-DEC Wastewater Management Program

Residual Waste and Biosolids

"Residual waste", as used in Vermont, is a term encompassing several waste materials. Primary among these is "sewage sludge" (which will simply be called "sludge" herein) - the solid, semi-solid, or liquid byproduct produced by the treatment of sewage in a Wastewater Treatment Facility (WWTF); and "septage" - the partially treated waste removed from an on-site septic system or holding tank.

"Biosolids" is defined as sludge which has been subjected to a treatment process for the reduction of pathogens and has been shown to meet the applicable requirements for contaminant concentrations, vector attraction reduction, and pathogen reduction, as necessary for the intended use, such as application to the land under a site specific permit or marketing and distribution to the general public for unregulated use.

"EQ biosolids", or Exceptional Quality biosolids, is defined as sludge or biosolids that have been subjected to an advanced pathogen reduction treatment process and meet the vector attraction and pollutant concentration standards such that they are no longer classified as a solid waste and may be marketed and distributed to the general public for use without a site specific permit.

"Secondary residual wastes" include wood ash, short paper fiber, sludge produced by the biological treatment of non-pathogenic dairy wastes, and sludge produced by the treatment of drinking water supplies. The management of secondary residual wastes is beyond the scope of this paper.

The three primary management options for sludge or biosolids that are currently available to Vermont WWTFs are land application after an approved pathogen treatment process, landfilling, or incineration. Although there are several emerging technologies that offer alternative strategies for sludge management (most of which generally fit into those three basic categories), none are currently sited where their use is economically feasible for Vermont municipalities and relatively few are being operated as full scale facilities with a documentable track record of their capabilities.

All residual wastes can potentially be managed by application to agricultural or silvicultural lands as a valuable nutrient source and soil conditioner. The use of human wastes (night soil) as a fertilizer dates back thousands of years and land application of biosolids resulting from wastewater treatment has been practiced since sewage sludge was first produced (Hartman, 1975). Research into the plant nutrient value of sludge spans several decades (Rudolfs and Gehm 1942, Dowdy et al. 1976, Sommers et al. 1977, Page et al. 1987, Logsdon 1993 (as cited by National Research Council of the American Academies of Science 1996) and Chambers et al. 2007). The noted benefits of biosolids as a soil amendment to agricultural land include a supply of plant essential macro and micronutrients, addition of organic matter to soil, reduced soil erosion, increased water holding capacity, and improvement of soil structure – all of which result in increased soil fertility and crop yields.

Additionally, some benefits of reusing biosolids include conserving space in and reducing greenhouse gas emissions from landfills. Methane emissions from landfills accounted for approximately 18 percent of the total US anthropogenic emissions in 2012, the third largest contribution of any methane source (USEPA 2014). A recent study (Beecher 2008) compared greenhouse gas emissions from different biosolids management options for the Town of Merrimack, NH concluding that landfilling biosolids would produce roughly 2.5 to 3.4 times more methane than composting. Furthermore, although land applied biosolids will decompose under aerobic conditions and produce carbon dioxide rather than methane (which is about 23 times more potent than carbon dioxide as a greenhouse gas) as the end metabolic product, the substitution of biosolids for fossil-fuel based commercial fertilizers and the carbon sequestration in soils resulting from land application can actually result in a net credit of greenhouse gas (American Society for Microbiology 2011, Canadian Council of Ministers of the Environment 2009). Biosolids are also used in the preparation of manufactured top soils and in land reclamation projects. Brown et al. (2004, 2005) utilized biosolids to reduce the phyto and bioavailability of lead, zinc and cadmium in smelter contaminated soils and alluvial tailings from mining operations. Similarly, Ryan et al. (2004) applied iron-rich biosolids to an urban lot contaminated with lead to successfully reduce lead bioavailability and exposure risk.

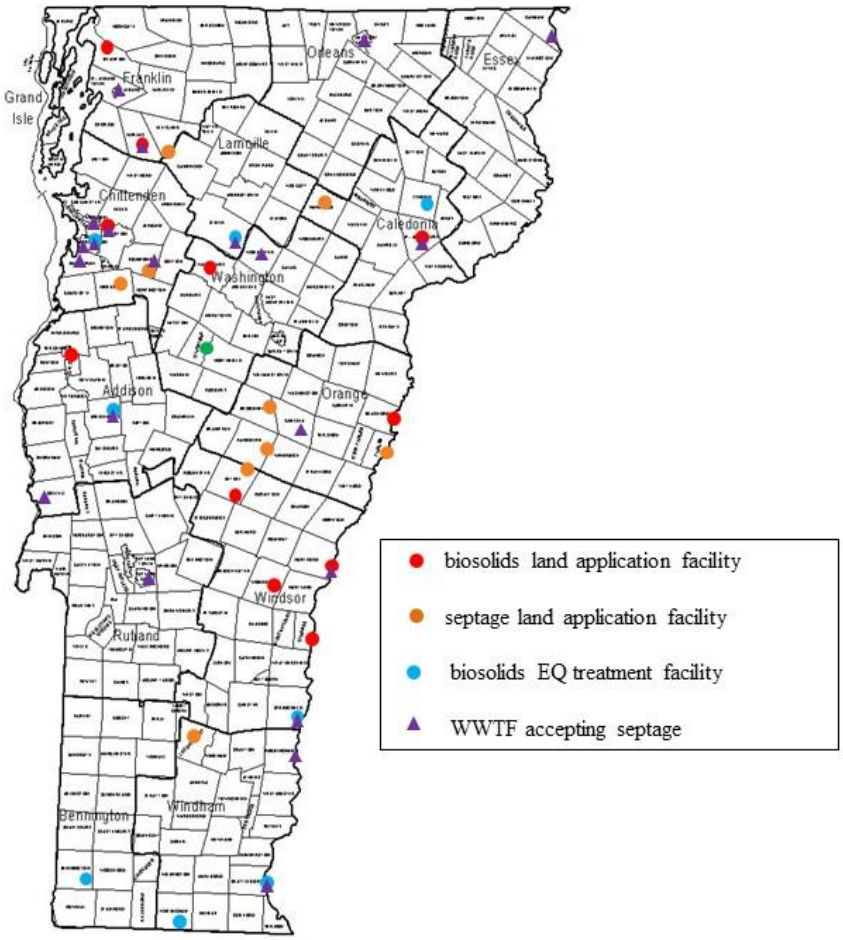
Because the land application of biosolids combines cost effective management of these abundant materials with the return of valuable nutrients back to the soil and the enhancement of soil properties and plant yield, the beneficial use of residual wastes has historically been an objective for the management of these materials at both the Federal and State levels. Indeed, the Vermont statutes at 10 V.S.A. 6604 (c)

stipulate that a section of the Vermont Solid Waste Management Plan *"shall set forth a comprehensive statewide program for the collection, treatment, beneficial use, and disposal of septage and sludge."*

Current Biosolids Management: U.S., New England and Vermont

Approximately half of all sludge produced in the United States (~7.1M dry tons per year) is treated to biosolids standards and land applied on less than one percent of the nation's agricultural acreage in crop production (USEPA 2012). In Vermont, approximately 1,000 acres of agricultural land is certified for the land application of biosolids and septage (approximately 780 and 220 acres, respectively), representing about 0.08% of the state's estimated 1.25 million acres in agriculture (Figure 1) (USDA 2014).

Figure 1. Location of Vermont's biosolids and septage management facilities.



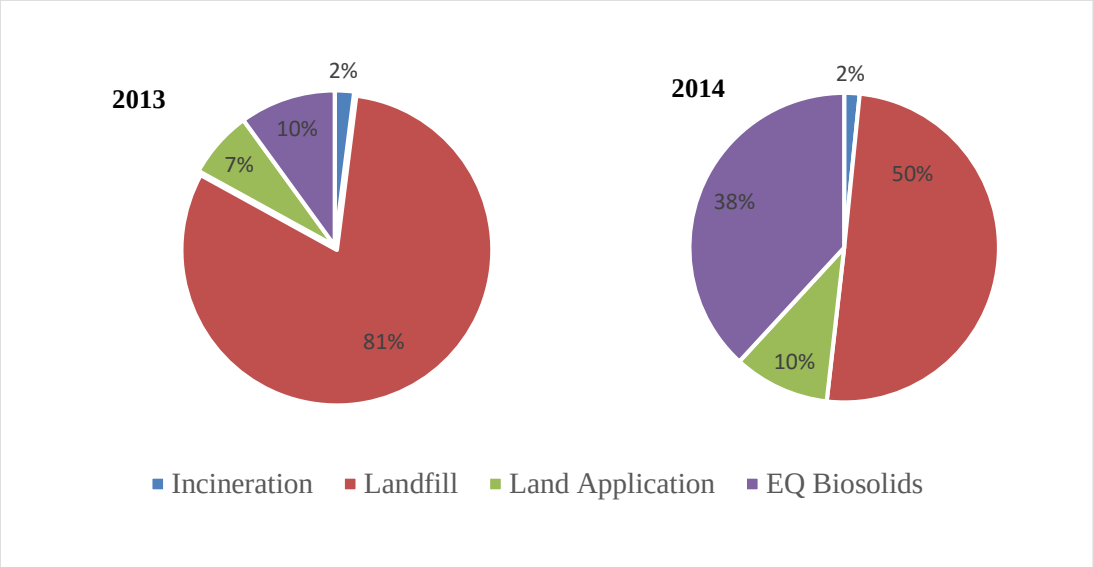
The management of biosolids in New England generally follows a trend where southern New England states incinerate most of the sludge produced at their WWTFs while northern New England states rely on a diversity of disposal and beneficial uses (Beecher 2012). For example, in 2011, Connecticut and Rhode Island incinerated the vast majority of the sludge produced in those states while Maine and New Hampshire reused about 74% and 66%, respectively, of those states' biosolids via land application after composting or an equivalent pathogen reduction treatment (Table 1).

Table 1. Sludge disposal option percentages (%) and dry weights by New England states in 2011.

	CT	MA	ME	NH	RI	VT
Incinerate	99	36	0	16	76	2
Landfill	0	25	26	18	2	69
Reuse (land app and EQ biosolids)	1	49	74	66	22	29
Dry Weight (dry US Tons/year)	118000	201700	29900	28300	27500	8400

In 2011, Vermont's ninety-four municipal WWTFs treated in excess of 15.5 billion gallons of sewage which resulted in the generation of approximately 56,000 wet tons of sludge (8,400 dry tons). Of this total, about 29% was treated to biosolids standards and used in agronomic settings and about 69% was disposed by landfilling, the highest rate in New England. In 2013, only 17% of Vermont's sludge was treated to biosolids standards and used agronomically and 81% was disposed by landfilling. However, in 2014, Vermont's WWTFs similarly treated approximately 15.3 billion gallons of sewage which generated

Figure 2. Vermont biosolids disposals in 2013 and 2014



approximately 59,500 wet tons (8,900 dry tons) of biosolids, but slightly less than one half (48%) was used agronomically and only 50% was disposed by landfilling (Figure 2 and Appendix 3: Table A-5). For 2015, the percentages were essentially unchanged from 2014, although approximately 67,675 wet tons (9,850 dry tons) of sludge was produced from treating approximately 14.1 billion gallons of sewage. Those recent data indicate a trend where the total volume of sewage being treated is decreasing, but the volume of sludge being produced per gallon treated is increasing. This flow trend is most likely a result of diverting stormwater from sanitary sewers and reductions of infiltration and inflow in collection systems, with the additional sludge being generated due to a corresponding optimization of treatment process and the implementation of new nutrient (nitrogen and phosphorus) removal processes.

Vermont's biosolids agronomic use rate (both land application and distribution of EQ biosolids – ("Exceptional Quality (EQ) biosolids" are biosolids that have undergone advanced treatment such that they can be marketed and distributed to the general public for use on the land without having to obtain a permit to do so (see further discussion on pages 18) was 73.5% in 1999, but declined over the next fifteen years primarily as the result of a change in management of a majority of the sludge generated by Chittenden County municipal WWTFs that, until 2007, had been composted at facilities in the eastern townships of Quebec through a contract established by the Chittenden Solid Waste District (CSWD), but had subsequently been disposed in landfills. However, as of 2014, CSWD and Casella Organics have brokered a new agreement with WWTFs in Chittenden County that transfers sludge generated by most of these WWTFs to the Casella Organics Grasslands Facility in Chateauguay, NY, where sludge is treated to EQ biosolids standards via an advanced lime stabilization process and eventually land applied as a soil amendment. This shift in management strategy has increased Vermont's sludge reuse rate significantly, as is evidenced by the reuse rate increasing from 17% to 48% from 2013 to 2014 (Figure 2).

Although Vermont's universal recycling law, Act 148, does not include any specific targets for the diversion of residual wastes to beneficial uses and is silent as to its applicability to banning sludge from landfills, any decision on its applicability to sludge and septage will be considerable, as a beneficial use rate of 75% remains the standard that the Vermont Agency of Natural Resources (ANR) would like to see accomplished (and would leave land application or incineration as the only remaining options for the disposal of sludge and biosolids).

57.5% of Vermont residences utilize on-site septic systems, the highest percentage in the United States (US Census Bureau 1990). Approximately 52 million gallons of septage was pumped from Vermont's on-site septic systems in 2015 and disposed as shown in Appendix 4: Table A-6.

Tables A-5 of Appendix 3 and A-6 of Appendix 4 provide breakdowns of sludge and septage management in Vermont in 2015. These tables show how those wastes were managed both in-state and out-of-state for the various management options available.

For an overview of biosolids management from a more global perspective, the report prepared by the United Nations Human Settlements Programme and the Greater Moncton Sewerage Commission (New Brunswick, Canada) provides descriptions of how biosolids are managed in thirty-seven other nations and the European Union. A synopsis of regulatory limits for biosolids used in agriculture from a number of those nations is provided in Appendix 8: Table A-11.

Biosolids Regulation: Federal and Vermont

Before Congress enacted the Ocean Dumping Ban Act of 1988, which banned the practice after 1991, wastewater sludge generated in the northeastern United States (except for Vermont and other interior regions) was typically disposed by ocean dumping. For example, starting in the 1920's, sludge generated in New York City was dumped into the relatively shallow waters of New York Harbor only12 miles offshore until the United States Environmental Protection Agency (EPA) established the Deepwater Municipal Sludge Site, also called the "106-mile Site", on the edge of the continental shelf (average depth of 7500 feet), where at least 40 million wet tons of sludge was deposited between 1986 and the end of 1991 (Specter 1992).

Although the Program was not able to locate definitive records, the first WWTF in Vermont likely was constructed in the late 1940s by the City of St. Albans (although the City of Burlington also lays claim to that honor with the City's first plant completed in 1953 and equipped with anaerobic sludge digestion), but it was not until the late-1950s through the mid-1960s that WWTF construction throughout Vermont began in earnest and the discharge of untreated sewage directly into Vermont's waterways came to an end. At that time, solids management was unregulated under both Vermont's and federal regulations, and it is assumed (although not documented) that most solids were either land applied on local farm fields or disposed in the numerous unlined local landfills that existed at the time.

The formal regulation of sludge management in Vermont was first addressed in April 1962 when the Vermont Department of Health (VDOH) issued a one paragraph regulation that was based on public health protection. From that date through the early 1970s, sludge produced by Vermont's WWTFs was managed based solely on its pathogenic nature, primarily via land application. Draft Vermont Guidelines for solids management were first developed by DEC in the early 1970s to supplement the regulation and included basic management practices and the first numerical limits on pollutants.

In 1979, the Code of Federal Regulations (CFR) Title 40, Part 257, the first federal regulations for the application of solid wastes to agricultural lands, was promulgated. Part 257 contained numerical limits only for cadmium and polychlorinated biphenyls (PCBs) and established the first pathogen reduction treatment options. The 1981 revisions to the Vermont Guidelines established additional "best practices" and pollutant standards, and adopted the pathogen reduction requirements of Part 257.

In 1989, the first Vermont Solid Waste Management Rules (VSWMR) were promulgated, establishing most of the recommended practices in the Guidelines as a formal regulation. The VSWMR have been revised seven times since they were first promulgated, most recently in March 2012, with most revisions including some enhancements to the sludge/biosolids management regulations.

In February 1993, 40 CFR Part 503, *"Standards for the Use or Disposal of Sewage Sludge"*, was promulgated as a standalone regulation for sludge management and disposal, some twenty years after the EPA first developed sludge management regulations under Section 405 of the 1972 Federal Pollution Control Act (and through amendments to the Act in 1977 and 1987) (USEPA 1993, 1994). Under 40 CFR Part 503, biosolids disposal became a highly regulated management practice. Part 503 establishes requirements for the disposal of biosolids when they are applied to the land to condition the soil or provide nutrients. Part 503 also establishes specific regulations for surface disposal and incineration – neither of which is a management practice for which facilities are sited in Vermont. "Surface disposal", as defined in Part 503, refers to what is essentially a sludge-only landfill. All sludge disposed in Vermont landfills is disposed in municipal solid waste landfills, which are regulated under 40 CFR Part 258.

In 1998, Vermont submitted an application to EPA seeking federal delegation to administer its sludge management programs. The delegation request was submitted for authority under Part 257 because sludge is defined as a solid waste under Vermont statute. Vermont was the last state that EPA allowed to do so. In most states, sludge management is regulated under their National Pollutant Discharge Elimination System (NPDES) authority, and the seven states currently delegated to administer the biosolids program for EPA are delegated under the authority of Part 503. However, due to the legalistic conflicts between Parts 503 and 257, Vermont's delegation request has been stalled in EPA's hands since the early-2000s. As of the date of this white paper, Vermont is no longer actively pursuing federal delegation for the program, although it has not formally withdrawn its delegation petition.

Beginning in FY2012, EPA began disinvesting in the biosolids management programs regulated under Part 503 under the guise that "the Rule is sufficiently protective of human health and the environment and is self-implementing". The primary areas of disinvestment are in EPA's Office of Enforcement and Compliance Assistance (OECA), the number of FTEs dedicated to the biosolids program at EPA headquarters and in the regional offices, and in providing ongoing technical support and training for the states' regulatory staff. EPA Region 1 currently allots 0.1 FTE to its biosolids program. Although EPA's Office of Science and Technology still performs the biennial reviews required under the Clean Water Act (CWA) and continues to support the Pathogen Equivalency Committee, EPA otherwise believes that it is capable of ensuring compliance with the regulation through the monitoring, reporting, and recordkeeping requirements of Part 503. However, since 40 CFR 503.18 only requires Class 1 WWTFs (defined as those with a design flow of greater than one million gallons per day or which serve a population of 10,000 people or more - only 30 of the 94 municipal WWTFs in Vermont) to submit an annual report to EPA of their sludge management activities (with no reporting requirement at all for non-Class 1 WWTFs) most Vermont WWTFs receive no federal oversight of their biosolids management activities. And, considering that EPA lacks the staff necessary to conduct timely reviews of those Class 1 facility reports and the fact that there have been no biosolids program inspections conducted by EPA in Vermont in more than 25 years, in essence Vermont WWTFs receive no federal oversight of their biosolids programs.

In Vermont, the VSWMR requires that all facilities must submit reports of their biosolids or septage management activities and monitoring data on a quarterly (4X per year) basis, and all quarterly reports are reviewed by Program staff within 30 days of their receipt.

So, for all practical purposes EPA's disinvestment in its biosolids programs will have no impact on Vermont's program since DEC has for more than 25 years been the sole authority administering and enforcing this program in Vermont.

The process of identifying potential pollutants for regulation under Part 503 began in 1984 when EPA developed a list of 200 chemicals for consideration based on available data concerning:

- Human exposure and health effects
- Plant uptake
- Phytotoxicity
- Effects on domestic animals and wildlife
- Effects on aquatic organisms
- Frequency of occurrence in sludge
- The probability that the pollutant would be toxic when exposure occurred through the use or disposal of biosolids
- The availability of toxicity and exposure data

The initial screening eliminated 150 of the originally listed pollutants, due to either their having been banned from production and use in the United States, their low frequency of occurrence/low concentrations in sludge, or because there was insufficient exposure and toxicity data to make an evaluation; as Congress, in crafting the CWA, specifically established in Section 405 that contaminant standards must be developed:

> *"on the basis of* ***available information*** *on their toxicity, persistence, concentration, mobility, or potential for exposure, may be present in sewage sludge in concentrations which may adversely affect public health or the environment"* (***emphasis*** added)

For each of the remaining 50 pollutants, EPA developed a Hazard Profile that ranked each based on the estimated concentration of the pollutant in soil, plant or animal tissue, groundwater, surface water, or air; and the lowest concentration of the pollutant shown to be toxic via the most sensitive route of exposure. Every pollutant that was scored with a Hazard Rating of greater than 1 (the range was <1 to >1000) was subjected to the detailed risk assessment described briefly below.

To protect public human, animal, soil and crop health from pollutants that are typically present in municipal biosolids, EPA conducted an extensive deterministic risk assessment on the pollutants remaining from the original list using fourteen potential exposure pathways. Ultimately, EPA determined that only 10 of the remaining 50 potential pollutants met the criteria that allowed and required EPA to establish regulatory limits for them, and EPA subsequently set numeric limits for the ten trace elements [Arsenic (As), Cadmium (Cd), Chromium (Cr), Copper (Cu), Lead (Pb), Mercury (Hg), Molybdenum (Mo), Nickel (Ni), Selenium (Se) and Zinc (Zn)] with high enough potential risk to warrant regulation (Table 2). The Part 503 technical support documents, in two volumes, detail the risk assessment's underlying science (TSD - Vol. 1 and TSD - Vol. 2). EPA has also prepared a document, *"A Guide to the Biosolids Risk Assessment for the EPA Part 503 Rule"* (USEPA 1995).

Table 2. Exposure Pathways used in Land Application Risk Assessment.

Exposure Pathway	Description of Highly Exposed Individual	Metal limiting pathway
Biosolids>soil>plant>human	Human (not home gardener) lifetime ingestion of plants grown in amended soil	None
Biosolids>soil>plant>human	Human (home gardener) lifetime ingestion of plants grown in amended soil	None
Biosolids>human	Child directly ingesting biosolids	**As, Cd, Pb, Hg, Se**
Biosolids>soil>plant>animal>human	Human lifetime ingestion of animal products raised on forage grown on biosolids amended soil	None
Biosolids>soil>animal>human	Human lifetime ingestion of animal products from animals directly ingesting biosolids	None
Biosolids>soil>plant>animal	Animal lifetime ingestion of plants grown on biosolids amended soil	**Mo**
Biosolids>soil>animal	Animal lifetime direct ingestion of biosolids	None
Biosolids>soil>plant	Plant toxicity from biosolids amended soil	**Cr, Cu, Ni, Zn**

Biosolids>soil>soil organism	Soil organism ingestion of soil/biosolids mix	None
Biosolids>soil>soil organism>soil organism predator	Predator of soil organisms that have ingested biosolids amended soil	None
Biosolids>soil>airborne dust>human	Adult human lifetime inhalation of dust from biosolids amended soil	None
Biosolids>soil>surface water>human	Human lifetime drinking surface water and ingestion of fish contaminated with pollutants in biosolids	None
Biosolids>air>human	Human lifetime inhalation of pollutants in biosolids that volatilize to air	None
Biosolids>soil>groundwater>human	Human lifetime drinking well water containing pollutants leached from biosolids	None

A more detailed description of each Highly Exposed Individual is presented in Appendix 1.

The modelling used by EPA, and the conclusions it used for development of the regulation were independently reviewed by both the Program, VDOH, and the National Academy of Science's National Research Council. Those independent reviews concluded that the initial modelling, which employed a deterministic risk analysis approach was generally sufficient to assure public health and safety and to protect the environment for the ten metals for which standards were ultimately promulgated. EPA switched to using a probabilistic Monte Carlo type approach in subsequent models to refine the risk analysis and verify the results of the initial deterministic modelling. VDOH and the Program did express concerns regarding the concentration limits established for arsenic and cadmium (discussed later in this paper), and Vermont's standards were accordingly promulgated at lower concentrations than those in Part 503. Similar concerns were also one of the primary justifications for Vermont adopting a single tier of contaminant standards at levels lower than the absolute ceiling concentrations established in Part 503.13 – Table 1, which neither the Program nor VDOH considered to be acceptable.

One significant, and perhaps the most misunderstood, set of parameters in EPA's exposure pathway modelling centers around how the limits were calculated, the level of risk employed in setting the standards, the population to which those risk levels were applied, and how the risk relates to the general population. Translating risk into everyday language is a difficult undertaking and for the purposes of biosolids, it is further confounded by the necessity to consider both non-cancer risk as well as cancer risk. EPA, in the 'Questions and Answers' section of its document "A Guide to the Biosolids Risk Assessments for the EPA Part 503 Rule" (1994) provided one of the clearer explanations (at pages 109 – 111 of that document) through the series of questions and answers provided below (slightly edited for clarification and updated population estimates).

> Q: What does an incremental cancer risk level of 1×10^{-4} mean?
>
> A: For carcinogenic compounds, a 1×10^{-4} incremental lifetime cancer risk means there is an increase in the probability of a hypothetical Highly Exposed Individual getting cancer due to exposure to biosolids of 1 in 10,000.

Q: Does this 1 X 10^{-4} risk level mean that as a result of the Part 503 biosolids rule, 32,000 of the 320 million persons living in the United States (1 person for each 10,000 persons) could possibly get cancer because of exposure to biosolids?

A: No, the risk of getting cancer is related only to the population that is exposed to that risk. In the United States, the number of persons highly exposed to biosolids is actually very small. If, for example, 10,000 individuals were in the population of hypothetical Highly Exposed Individuals, then there might potentially be one case of cancer arising in that population from exposure to a particular pollutant in biosolids. If, however, the population of hypothetical Highly Exposed Individuals was 10, then there might potentially be 0.001 case of cancer arising in the population of hypothetical Highly Exposed Individuals from that pollutant.

Q: Were the limits for metals in the Part 503 Rule established based on an incremental lifetime cancer risk of 1 X 10^{-4}?

A: No, the Part 503 metals were considered noncarcinogens (they do not cause or induce cancer) for the exposure pathways evaluated.

Q: If the metal limits were not based on an incremental cancer risk of 1 X 10^{-4}, then on what basis were they set?

A: The pollutant limits for each of the Part 503 metals in biosolids are based on threshold limits such as risk reference doses (RfDs) which represent the amount of daily intake of a particular non-cancer causing substance that is not expected to cause adverse effects; the RfD is a conservative determination of the upper level of acceptable intake. The RfD (or other threshold limit) was then combined with pollutant intake information (for example, the amount of a pollutant in biosolids taken up by plants that are then ingested by humans; the amount of a particular food consumed) to derive a pollutant limit. Each pollutant limit, all of which are assumed to be highly conservative, are set to protect a hypothetical Highly Exposed Individual (a different human, plant or animal in each of the 14 exposure pathways) from any reasonably anticipated adverse effects of a pollutant.

So, to recap, the risk of adverse health effects due to exposure to biosolids is directly proportional to the level of exposure. If there is no exposure, which is the case for the vast majority of the country's population, then there is no risk of adverse health effects from biosolids. And so, while the cancer risks were modelled at a target risk level of 1 X 10^{-4} and non-cancer risks were modelled based on threshold limits such as RfDs (which are assumed to be conservative), it must be kept in mind that the pollutant limits were based on the risk for a *hypothetical Highly Exposed Individual* receiving the full exposure used as the model's basis and that actual populations of hypothetical Highly Exposed Individuals in the United States range in size from only a fraction of a person to several persons. In other words, the pollutant limits were set at a level that is protective for the extremely small subset of the U.S. population having the highest level of exposure to biosolids. It therefore follows that the risk of adverse effects to the *general population* derived from biosolids management is exceedingly small and in most cases is approaching (or at) a discernable risk of 'none'.

Both VDOH and the Program did, however, believe that there were several significant deficiencies in the modelling, mainly in that EPA did not have sufficient data to accurately model the risk derived from numerous organic compounds (including dioxins, for which the needed data was subsequently amassed and modelled by EPA), and radionuclides. Similar concerns were noted by several states and similarly

conveyed to EPA. In response EPA conducted several other studies over the period 1982 through 2006 in order to better characterize these other contaminants and to develop standards where appropriate. However, because of Section 405's restrictions, insufficient information has precluded EPA from accurately modelling and thereby establishing standards on many potential contaminants. Indeed, the standards established for molybdenum and chromium in Part 503 were vacated by federal court actions mainly on the basis that EPA was not able to demonstrate that the information available when the standards were developed was sufficient to satisfy this requirement of Section 405. As of the date of this paper, EPA is continuing to amass the data necessary to reestablish the molybdenum standard and to consider additional contaminants for regulation under Section 405's constrictions. While the Program recognizes the limitations this places upon EPA and its legal authority to establish standards for other compounds, Vermont simply does not currently have the staffing and expertise that would be necessary to develop appropriate risk based standards for such contaminants of its own volition.

As a result of EPA's legal preclusion from establishing a more comprehensive set of standards due to inadequate data, policy based decisions in Vermont, as well as in many other states, have led to the adoption of biosolids regulations that are more restrictive than the federal Part 503 rule in order to further safeguard public health and the environment (NEBRA 2007). Tables comparing the Non-EQ and EQ biosolids contaminant limits in each of the fifty states are presented in Appendix 7: Tables A-9 and A-10.

Vermont regulates biosolids and residual wastes under the Vermont Solid Waste Management Rules (the current version became effective 3/15/12) (VSWMR) and has adopted more stringent standards for the diffuse disposal (the term used in the VSWMR for 'land application') of biosolids (Tables 3 - 6). In practice, biosolids management in Vermont is regulated at the most conservative standards established under either the VSWMR or Part 503. For example, Vermont has set pollutant concentrations in biosolids for arsenic, cadmium, and mercury that are lower than all federal levels, has retained its historical standard for polychlorinated biphenyls (PCBs), and has maintained the federal Table 3 standards for molybdenum and chromium despite their having being dropped from Table 3 of 40 CFR 503.13 due to federal court action (Molybdenum notice and Chromium Decision).

Under 40 CFR 503.13, two tiers of contaminant concentrations are established: 503.13 - Table 1 (the higher ceiling concentrations for biosolids that can be applied to permitted, controlled sites); and 503.13 - Table 3 (the lower maximum concentration of contaminants in biosolids that can be marketed and distributed to the general population as an unregulated commodity). Vermont has adopted one tier of contaminant standards (§6-702 VSWMR) for all biosolids that are to be applied to the land or marketed and distributed to the general public that are more stringent than or equal to the more conservative standards in 503.13 – Table 3.

Table 3. Comparison of Federal and Vermont pollutant concentration (mg/kg, dry wt.) standards for land application of biosolids.

	As	Cd	Cr	Cu	Pb	Hg	Mo	Ni	Se	Zn	PCB
503.13 – Table 1	75	85	N/R	4300	840	57	75	420	100	7500	N/R*
503.13 – Table 3	41	39	N/R	1500	300	17	N/R	420	100	2800	N/R*
Vermont	15	21	1200	1500	300	10	75	420	100	2800	10

N/R = no regulatory standard established.
* No standard established in Part 503, but *any* waste containing >50 mg/kg PCB *must* be managed per 40 CFR Part 761.

As stated above, Vermont DEC has opted to take the more conservative approach and to retain standards for chromium and molybdenum despite federal court action that vacated those standards in Part 503. Industry lawsuits were successful in convincing the federal court that the chromium standard was not risk based (as required by the CWA) in that there is no evidence that chromium in sludge exists in the toxic and carcinogenic hexavalent (Cr^{+6}) form (in sludge, it exists only in the non-toxic trivalent or elemental forms) and that the risk to grazing animals from molybdenum was inconsequential when the copper concentration met the Table 3 standard. Before Part 503 was promulgated, Vermont had already adopted a lower cadmium standard of 25 mg/kg (dry wt.) in the VSWMR. The cadmium limit was then lowered to 21 mg/kg (dry wt.) in a subsequent rule revision due to concerns raised by Dr. Rufus Chaney and the United States Department of Agriculture (USDA) regarding potential export restrictions on grains and sunflower kernel to the European Union, which has adopted extremely low limits for cadmium in those commodities. The lower Vermont standard of 15 mg/kg (dry wt.) for arsenic was adopted after Part 503's promulgation due to the VDOH's concerns regarding perceived deficiencies in how the Part 503 risk assessment dealt with the carcinogenic potential of inorganic arsenic compounds (Southworth 1995).

Because there is scant research into which form of arsenic compounds exist in sludge (non-carcinogenic organic vs. carcinogenic inorganic compounds), VDOH opted to again take a conservative approach and assume that all arsenic in sludge exists as carcinogenic inorganic compounds and determined that it was appropriate to establish a standard on that basis. Although VDOH's analysis concluded that an arsenic standard of 10 mg/kg (dry wt.) was appropriate; the complex, organic rich matrix of biosolids produces analytical interferences such that laboratories (at the time that the standard was adopted) were unable to reliably attain detection limits at that concentration. As a result, the arsenic standard was established at 15 mg/kg (dry wt.) in the VSWMR, the lowest limit that laboratories could reliably achieve in order for permittees to be able to definitively demonstrate compliance. The historic standard of 10 mg/kg (dry wt.) for mercury established in early versions of the VSWMR was retained in the current Rule. Similarly, the historic standard of 10 mg/kg (dry wt.) for PCB established in early versions of the VSWMR was retained. Part 503 has never contained a standard for PCBs, although biosolids (or any wastes) containing PCBs in concentrations of 50 mg/kg (dry wt.) or greater must be disposed in accordance with 40 CFR Part 761.

Part 503.13 - Table 4 establishes Annual Pollutant Loading Rates (APLR) for any biosolids that are applied to the land under the 503.13 – Table 1 ceiling concentrations. The APLRs limit the mass of the regulated pollutants that may be applied to a site in any 365-day period. Since Vermont has not adopted the two tiered Table1/Table 3 approach to contaminant standards, and because it is virtually impossible to load a site to the APLR limits under the 503.13 – Table 3 or Vermont pollutant limits when agronomic application rates are observed, Vermont does not regulate based on the federal APLR limits. The only exception to this is that the VSWMR has always had an established APLR for cadmium of 0.45 lbs Cd/ac-year (derived from 40 CFR Part 257). Any other APLRs based on concerns held by the Vermont Agency of Agriculture, Food, & Markets (VAAFM) should be considered.

40 CFR 503.13 - Table 2 establishes Cumulative Pollutant Loading Rates (CPLR), the maximum mass of a pollutant that may be applied per acre (or hectare), for biosolids that are applied to the land (Table 4). With the exceptions of cadmium, where the VSWMRs has retained its historic standard (again, derived from 40 CFR Part 257) of 4.5 lbs Cd/acre (5.0 kg Cd/hectare) compared to the federal standard of 39 kg Cd/hectare (34.7 lbs Cd/acre); chromium and molybdenum, where Vermont continues to enforce the CPLRs for these contaminants that were vacated by the federal court action; and arsenic, where the federal CPLR was decreased in proportion to the reduced ceiling concentration (from 75 kg As/hectare down to 15 kg As/hectare); Vermont observes the federal standards despite having not yet been formally adopted in the VSWMR.

Table 4. Vermont Cumulative Pollutant Loading Rate Limits (kg/ha). *

As	Cd	Cr	Cu	Pb	Hg	Mo	Ni	Se	Zn
15	5	1200	1500	300	17	75	420	100	2800

*Note: kg/ha x 0.89 = lbs/acre; 1 hectare (ha) = 2.47 acres

Application rates for biosolids and septage are strictly controlled. The Program has developed an Excel® based spreadsheet model (Application Rate Model) for calculating application rates based on both nitrogen and phosphorus. Historically, application rates have been calculated based solely on the nitrogen content of the biosolids with respect to the annual nitrogen requirement of the crop being grown on the site, with the ultimate goal being a net balance of 'zero' between the mass of nitrogen applied and the amount removed by the crop. Additionally, although not required under the VSWMR, the Program requires that the application of biosolids to all permitted sites must be done under an approved Nutrient Management Plan. This is generally accomplished by including biosolids management as a part of the farm's approved NRCS Nutrient Management Plan.

Due to developing concerns regarding the potential for phosphorus transport from agricultural lands to surface waters, especially in the Lake Champlain basin with the establishment of a total maximum daily load (TMDL) for phosphorus and with excessive phosphorus levels in agricultural soils, the Program has expanded the model to include phosphorus as a potentially limiting nutrient. Work is currently progressing by staff at the VAAFM's Agricultural & Environmental Testing Lab on revisions to the Vermont Phosphorus Index (for biosolids, the incorporation of a source code to account for the difference in phosphorus solubility based on whether the WWTF employs biological phosphorus removal versus a chemical precipitation process), a task that must be accomplished in order to obtain accurate application rates from the phosphorus side of the application rate model. By the end of 2016, application rates will be based on the more restrictive of these two nutrients. Although the water extractable phosphorus (WEP) content of biosolids, a key indicator of their potential to release phosphorus to runoff, is far lower than manure (3% in digested biosolids vs. 48% in dairy manure) (Moss et al. 2002), the implementation of application rates based on biosolids' phosphorus content could potentially present additional challenges to existing land application programs. Typically, in cases where phosphorus is the limiting nutrient, it is not due to crop nutrient requirements, but rather to either a pre-existing overabundance of phosphorus in a site's soils or because the site features highly erodible soils proximate to surface water. Biological phosphorus removal results in higher concentrations of phosphorus in biosolids, and a large majority of the phosphorus exist in a form that is relatively soluble in water and immediately plant available. This results in a significantly reduced application rate and a correspondingly greater acreage need per unit volume of biosolids.

Removal of phosphorus by chemical precipitation results in a sludge that is predominantly insoluble in water and, while increasing the overall amount of sludge produced by a WWTF, will not have the same impact on land application programs because the two sludge streams typically are not intermingled and the Program has generally not allowed the management of sludges produced by the chemical precipitation of phosphorus because they usually have minimal nutrient value. These sludges are typically disposed in a landfill, so a substantial increase in the volume so disposed is expected. The Program is, however, exploring the potential use of these precipitate sludges as a method of immobilizing soluble phosphorus in soils where the phosphorus concentration is excessive. Any such use would only be approved following close consultation with VAAFM and their approval of using the precipitate sludge for that purpose.

Vermont's land application site monitoring requirements also go beyond the federal requirements established in 40 CFR 503.16, including annual or bi-annual soil and groundwater testing, as well as plant (forage) analysis once each certification period (Table 5). Under 503.16, the large majority of Vermont's WWTFs would only be required to monitor the quality of their biosolids once per year, based on their low biosolids production rates. Vermont is one of the few states that requires groundwater monitoring at land application sites and is the only state that requires periodic testing of the plant tissue of crops raised on land application sites.

Table 5. Comparison of Vermont and Federal monitoring requirements for land application sites.

Media	Vermont	40 CFR 503.16
Biosolids	Every batch applied or a minimum of once per year	Varies based on mass produced
Groundwater	Minimum: once per year	None
Soil	Minimum: once per year	None
Plant Tissue	Once per permit cycle	None

Operators of land application sites are also required to install a network of groundwater monitoring wells, minimally comprising of one up gradient and two down gradient wells, to enable a comparison of the quality of ground water entering and then exiting a site after flowing under the active application area. The Program has amassed over 25 years of monitoring data documenting the effects (or lack thereof) of land application on groundwater beneath such sites. In addition, minimum isolation distances established under the VSWMR at §6-503 are either stricter than the corresponding federal standard (503.14) or are established where no federal standards exist (Table 6).

Table 6. Comparison of Vermont and Federal minimum required isolation distance (in feet) requirements.

Distance to	Vermont	40 CFR 503
Water table at time of application	3	None
Bedrock	3	None
Surface water	100	10 meters (~33 ft.)
Property line	50	None
Residences, schools, etc.	100	None
Drinking water sources *	300	None

* may be reduced if the facility is hydrologically down gradient of the source

The VSWMR, in Subchapter 5, also establishes that (* with certain case-by-case specific minor exceptions) sludge or biosolids management facilities may not be sited in the following designated areas:

- in Class I and Class II Groundwater areas
- in Class I and Class II wetlands and associated buffers, absent a Conditional Use Determination
- in Class III wetlands, absent a Part 401 Water Quality Certification
- in a National Wildlife Refuge

- in a Wildlife Management Area administered by the Vermont Department of Fish & Wildlife
- in a designated threatened or endangered species habitat
- in the watershed for a Class A Water
- within 500' of an Outstanding Natural Resource Water
- within Zone 1 or Zone 2* of a Public Water Supply Source Protection Area
- within the floodway portion of a 100-year floodplain.

The EPA also developed standards for pathogen reduction and vector attraction reduction (VAR), codified at 503.32 and 503.33, respectively, and determined appropriate treatment technologies capable of achieving these reductions prior to land applying biosolids.

The VAR standards were established by EPA as a means of setting criteria intended to demonstrate the degree by which the putresibility of the biosolids is reduced in the treatment process as a means of controlling the generation of nuisance odors, which are the main attractants for flies and other vermin that could potentially spread pathogens. Generally, the VAR options all measure the reduction in the amount of putrescible volatile solids in biosolids.

While Vermont accepts any of the twelve VAR demonstrations established under the federal regulation, the same is not the case for the pathogen reduction demonstrations established in Part 503.33. Under Part 503, two tiers of pathogen reduction standards are established – Class A and Class B, which are not universally accepted in Vermont.

Pathogen reduction is not measured by culturing and enumerating specific human pathogens, mainly due to the hazards of doing so and the scarcity of laboratories holding the federal permits and level of security necessary to culture such pathogens. Instead, indicator organisms – *fecal coliforms* and *salmonella s.p.*, bacteria that are ubiquitous in the environment, are used as surrogate indicators. *Salmonella s.p.* was selected because they are typically present in higher densities in sewage than other bacterial pathogens and are at least as resistant to treatment as other specific pathogens. *Fecal coliforms* are enteric bacteria that were selected because they are also present in high densities in raw sewage and, although not normally human pathogens, *fecal coliforms* are excellent indicators of the survivability of other truly pathogenic species in treatment processes.

Class B biosolids are comprised of sludge which has been subjected to a Process to Significantly Reduce Pathogens (PSRP), or an equivalent process approved by EPA's Pathogen Equivalency Committee (PEC) or the permitting authority (ANR, in the case of Vermont). However, in general, the Program is extremely hesitant to approve the use of any process (for Class B or Class A treatment) which has not been vetted and received an equivalency determination from the PEC. PSRP processes are typically low temperature aerobic or anaerobic digestion regimes or low temperature stabilization with hydrated lime, which result in the reduction – but not elimination, of pathogen indicator organisms in the biosolids. The targeted level of treatment for a PSRP results in a minimum of a two log (99%) reduction of the density of indicator organisms, *fecal coliforms* or *salmonella s.p.*. Because PSRP methods reduce, but do not eliminate, pathogens in biosolids; in Vermont, Class B biosolids may only be applied to sites which are specifically authorized for such use under a Solid Waste Management Facility Certification issued by ANR. Sites used for the management of Class B biosolids are also subject to a wide range of site use restrictions designed to further reduce the potential for public health and environmental hazards that could derive from contact with the Class B biosolids.

Permittees operating sites to which Class B biosolids or stabilized septage is applied are required to implement the following site use restrictions:

- application of biosolids to frozen or snow covered ground is prohibited
- application of biosolids where there is less than 36 inches of unsaturated soil is prohibited
- public access to the site must be restricted for a period of twelve months following the last application event (Note: the Rule requires "restricted" access, not "prohibited" access)
- the pH of the site's soil must be maintained in the range of 6.5 – 8.0 S.U.
- domestic food source animals may not be grazed on a biosolids amended site for a minimum of six months following the last application event
- sites may not be used for the production of crops for direct human consumption for a minimum of 36 months following the last application event (38 months if the harvested part grows below the ground surface, per Part 503)
- feed crops may not be harvested for a minimum of five weeks following the last application event
- silage grown on biosolids amended sites may not be fed to animals for a minimum of four months following the last application event
- turf grown on biosolids amended sites may not be harvested for a minimum of one year following the last application event

To the best of the Program's knowledge, neither Class B biosolids or septage are being used, or ever have been used, on sites producing crops for direct human consumption in Vermont.

Class A biosolids are comprised of sludge which has been subjected to a Process to Further Reduce Pathogens (PFRP) or again, an equivalent process approved by the PEC or the permitting authority. These processes typically entail high temperature aerobic or anaerobic digestion, heat drying, high temperature lime stabilization, or other thermal or chemical treatment processes that result in the reduction of pathogen indicator organism densities to below their test method's detection limits. PFRP methods are, in effect, pasteurization processes designed to virtually eliminate pathogens.

Under the federal regulation, the set of pathogen indicator organisms that may be selected for Class A demonstrations is expanded from the testing of *fecal coliform* or *salmonella s.p.* densities, the only indicator organisms allowed for Class B demonstrations, to include viable helminth (parasitic worms) ova and enteric viruses under Class A: Alternatives 3 and 4, neither of which include process based requirements. Of the six Class A alternative demonstrations established in Part 503, Vermont only accepts the four alternatives (Class A: Alternatives 1, 2, 5, and 6) that do include process based treatment requirements and that do not recognize the use of viable helminth ova or enteric viruses as indicator organisms. Vermont has adopted this approach for two main reasons: 1) in order to further assure pathogen kill, treatment in a process based on a time/temperature relationship or chemical environment necessary to assure pasteurization is requisite, and 2) recent research has shown that the density of viable helminth ova and/or enteric viruses in raw sewage is commonly sufficiently low such that it can meet the Class A standard absent any treatment for pathogen reduction. In other words, a demonstration of the absence of these organisms in treated biosolids, when they might not have been present in the raw sewage, is not a valid demonstration of the degree of pathogen reduction achieved by the process. In fact, EPA itself is considering deleting Class A: Alternatives 3 and 4 from the Part 503 regulation over those same concerns, primarily in relation to the issues surrounding the presence/absence of viable helminth ova and enteric viruses in raw sewage, which can result in the need to seed systems with these pathogen indicators ahead of the pathogen reduction treatment process in order to obtain usable data on the level of their destruction. The Program will not approve any processes that require seeding helminth ova or

enteric viruses (or any other pathogen indicator organisms) in order to have sufficient densities in the raw sewage for the ability to make a compliance demonstration in the treated biosolids.

Septage is also managed via land application in Vermont. Under Part 503, septage that may be managed via land application is restricted to *'domestic septage'*, defined in 503.9 as:

> *"material removed from a septic tank, cesspool, portable toilet, Type III marine sanitation device, or similar treatment works that receives only domestic sewage. Domestic septage does not include material removed from a septic tank, cesspool, portable toilet, Type III marine sanitation device, or similar treatment works that receives either commercial wastewater or industrial wastewater and does not include grease removed from a restaurant or grease trap."*

Vermont further restricts what it considers to be domestic septage by specifically prohibiting any cesspool, portable toilet, or Type III marine sanitation device wastes from being managed via land application, primarily because none of these wastes, unlike those contained in a traditional septic tank, has undergone an adequate degree of biological decomposition during their accumulation.

Domestic septage must also be subjected, at a minimum, to a Class B/PSRP pathogen reduction process prior to application to the land and is typically treated via the addition of hydrated lime by which the pH is raised to a minimum of 12.0 S.U. and held at that pH for a minimum of two hours prior to application. For septage, 40 CFR 503.32 (c)(2) requires only 30 minutes of exposure at this elevated pH (an "operational concession" to operators of septage land application programs), whereas the VSWMR has retained its historic two-hour standard, which predates the Part 503 regulation and matches Part 503's time requirement for lime stabilization of biosolids. Land application sites used for septage management are subject to the same site use restrictions as are sites used for the management of Class B biosolids.

Under both federal and state regulations, biosolids that have been treated to the Class A pathogen standards and meet the VAR and applicable contaminant standards (503.13 – Table 3 at the federal level or as established in the VSWMRs if produced in Vermont - see Table 3 of this paper) are no longer classified as a solid waste. Such biosolids are commonly referred to as "EQ biosolids" (for Exceptional Quality biosolids – a common misnomer is to call them "Class A biosolids", which actually refers solely to the degree of pathogen reduction), and those biosolids and/or products derived from them (such as manufactured topsoil) may be marketed and distributed to the general public for unrestricted use and application to the land without first having obtained a permit to do so from ANR [40 CFR 503.10 (g) and §6-301 (b)(5) of the VSWMR]. The EPA adopted this approach because it believes that the use of EQ biosolids is not likely to be a recurring event on any given parcel of land (thereby minimizing the potential for over application), that biosolids treated to Class A pathogen standards pose minimal risk to human health, that biosolids meeting the VAR requirements are not likely to create nuisance conditions or attract vermin, and that attainment of the 503.13 – Table 3 contaminant standards represents a minimal risk to exposed individuals. The VSWMRs have agreed with this concept throughout their existence, and there are currently seven municipal WWTFs that treat the biosolids they produce to EQ standards and market them to the general public (Bennington, Lyndon, Middlebury, South Burlington – Airport Parkway, Springfield, Stowe, and Wilmington). One additional facility (Brattleboro) is currently undergoing start-up testing and hopes to be EQ certified by the end of 2016, and one composting facility (Johnson) is currently mothballed with no immediate plans to resume operations for biosolids management although it is being considered for use in composting other non-sanitary organic wastes.

However, because the VSWMR, as currently written, only applies to facilities producing biosolids in Vermont under an ANR permit, an additional conflict between federal and Vermont regulations exists. Biosolids or biosolids products that are treated to EQ standards in facilities not located within Vermont may be imported into Vermont as an unregulated commodity provided they meet the more restrictive standards established under Part 503 or the operating permit of the facility in which they are produced, despite the fact that those standards may be less restrictive than the corresponding Vermont standards. Until such time as the VSWMR are revised (or supplanted for residual waste management by a new set of Vermont rules) to include a registration and approval program for out-of-state EQ biosolids using the same standards to which Vermont facilities are held, federal interstate commerce regulations preclude Vermont from prohibiting or otherwise restricting their importation and use. Currently, with no such registration and approval program in place, the Program has no idea of the source, volume, quality, or final uses of imported EQ biosolids and EQ biosolids products. It is a specific goal of this regulatory reform effort to develop and implement such a system. It is important to note that the only way Vermont could prohibit the importation and subsequent use of EQ biosolids and EQ biosolids products without running afoul of federal interstate commerce regulations is via an outright ban on applying any such material to the land in Vermont, regardless of its origin.

Current Permitting Requirements

In Vermont, all permitting requirements and procedures for sludge/biosolids and septage management are established under the VSWMRs (with the single exception regarding on-site disposal of material removed from composting toilets cited above). EPA – Region 1 is not issuing any permits under their Part 503 authority for sludge/biosolids or septage management except for facilities in the non-NPDES delegated states of Massachusetts and New Hampshire.

The VSWMRs allow for two basic permitting mechanisms: 1) Sludge Management Plans, or 2) Solid Waste Management Facility Certifications (Certifications).

Sludge Management Plans (SMP) are non-expiring, no fee, no public process approvals established under §3-301 of the VSWMR for WWTFs that dispose the sludge they produce at another suitable facility not under their control. Examples include sludge that is sent directly from a WWTF to incineration facilities, landfills, or other biosolids managers who provide secondary management under appropriate permits. SMPs are basic approvals for WWTFs that are not the end managers of the sludge, and only establish authorized secondary or end management facilities and basic sludge quality monitoring requirements.

Septage haulers who simply pump tanks and dispose of the septage at a WWTF, incineration facility, or transfer the septage to a secondary manager or transporter are only required to obtain a Vermont Waste Transporter Permit for their vehicles (10 V.S.A. §6607a) and to report their activities in accordance with §3-703 of the VSWMRs on a quarterly basis.

Any other means by which a WWTF or septage hauler manages sludge/biosolids or septage must be conducted under the authority of a Certification issued by ANR. These activities would include, but are not limited to: land application of Class B biosolids or septage, any type of processing to produce EQ biosolids for marketing and distribution to the general public, incineration, surface disposal under Part 503 – Subpart C, or storage outside the fenced area of a WWTF.

Certifications, which are valid for a maximum of 10 years, establish site authorizations and requirements for materials and site management practices, pathogen and VAR reduction process conditions and monitoring, media (waste quality, soil chemistry, groundwater chemistry, and plant tissue) monitoring and testing requirements and frequencies, quarterly reporting, and recordkeeping.

Innovative Toilet Technology

As mentioned in the "Introduction" section of this paper, an in-depth discussion of switching from centralized water based sewage collection and treatment systems to innovative waterless technologies such as DESAR systems (Decentralized Sanitation and Reuse), ECOSAN, Clivus Multrum, and other related products, is beyond the scope of this paper.

While there are unquestionably numerous advantages, which the Program does not dispute, that could be derived by separating purely sanitary sewage from the flow of other wastewater entering a WWTF and managing them as separate waste streams; absent any monitoring of treatment conditions and testing of the final product for pathogen indicator organism densities, these innovative systems provide no assurance of adequate pathogen kill other than their claim of compliance with the American National Standards Institute (ANSI)/National Sanitation Foundation's (NSF) Standard 41 (the text of which is only available if *purchased* from NSF and the requirements and standards established thereunder are not presented on any website of these technologies manufacturers). Compliance with ANSI/NSF Standard 41 is not recognized as an accepted PFRP process in Part 503, and no attempt has been made by ANSI/NSF or any manufacturers of these systems to obtain a Class A Pathogen Reduction Equivalency Determination from the PEC. EPA determined, and 503.32 establishes, that a minimum temperature of 50^{o} C must be attained for composting biosolids in order to achieve Class A pathogen reduction, yet the website of one major manufacturer of these units proclaims that *"temperatures inside the composting unit never exceed 100^{o}F"* (37.8^{o}C). Secondly, most non-incinerating innovative toilet technologies, primarily composting units, are single cell in design. This means that their design lacks a separate chamber in which the actual treatment process can take place without fresh pathogenic fecal material being constantly added. Because the Class A pathogen reduction standards (using Alternative 1 for composting toilets) establish a time/temperature relationship that must be met for *every particle* of sludge being treated, which at the minimum temperature of 50^{o}C requires 13.17 days of composting, the constant addition of fresh sewage means that the Class A pathogen reduction standard can never be met in single cell composting designs if they remain in use during active treatment. For those reasons, the Program and the VDOH agree that the waste removed from composting toilets that are not operated in compliance with the requirements of Part 503 for Class A pathogen reduction must be still be considered to be a pathogenic waste that may only be applied to the land as Class B biosolids under a site specific solid waste management facility certification issued by the DEC or in conformance with §1-922 of the Vermont Wastewater System and Potable Water Supply Rules (see the discussion on page 22 of this paper).

Modern WWTFs and the regulations under which they must function have provided one of the most effective means of preventing the spread of numerous fecal borne diseases - such as typhoid fever, cholera, dysentery, cryptosporidiosis, hepatitis, and polio; which were pandemic in their occurrence prior to the introduction of centralized wastewater collection and treatment systems and the introduction of antibiotics and vaccines effective against these diseases. Ineffective or improper operation of these innovative systems and the subsequent unregulated management of the material they produce would only serve to counteract the public health benefits provided by traditional WWTFs, the original and primary driver for their construction. Therefore, it is important to note that the treated material produced in these

waterless innovative systems, just as with sludge produced by traditional WWTFs, is fully regulated under 40 CFR Part 503 (see 503.1), 40 CFR Part 257, or 40 CFR Part 258 depending on its nature and how the material is disposed. And because these Parts, which in large were developed to provide similar safeguards against disease transmission resulting from solids management, specifically prohibit any state's regulations from being less stringent than the corresponding federal regulation, all non-federal jurisdictions are effectively precluded from regulating the "biosolids" these innovative systems produce less stringently than they regulate biosolids produced by a traditional WWTF. The applicability of Part 503 to the biosolids produced in alternative toilet systems is derived from both the "Purpose and Applicability" language (503.1) of the regulation, which establishes (**emphasis** added):

> *(b) Applicability. **(1) This part applies to any person who prepares sewage sludge, applies sewage sludge to the land**, or fires sewage sludge in a sewage sludge incinerator and to the owner/operator of a surface disposal site. **(2) This part applies to sewage sludge applied to the land**, placed on a surface disposal site, or fired in a sewage sludge incinerator. (3) This part applies to the exit gas from a sewage sludge incinerator stack. **(4) This part applies to land where sewage sludge is applied**, to a surface disposal site, and to a sewage sludge incinerator.*

and the "Definitions" section (503.9) of the regulation where:

'domestic sewage' is defined as:

> *"**waste** and wastewater **from humans** or household operations **that is discharged to or otherwise enters a treatment works**";* where,

'treatment works' is defined as:

> *"either a federally owned, publicly owned, **or privately owned device or system used to treat** (including recycle and reclaim) either **domestic sewage** or a combination of domestic sewage and industrial waste of a liquid nature"*; and

'sewage sludge' is defined as:

> *"the solid, semi-liquid, or liquid **residue generated during the treatment of domestic sewage in a treatment works".***

Part 503 does not provide any *de minimis* threshold for escaping regulation and specifically provides such at 503.3 (b), which states:

> ***"No person shall use or dispose of sewage sludge through any practice for which requirements are established in this part except in accordance with such requirements."***;

where 503.1 (a)(1) provides (in part):

> ***"Standards are included in this part for sewage sludge applied to the land…"***

where neither section provides any qualification or exclusions based on why the sludge is being applied to the land (nutrient value in an agronomic setting, soil conditioning, land reclamation, simple disposal, etc.).

On this basis, it is the Program's interpretation of this specific language in Part 503 that the material produced in such innovative systems may not be applied to the land unless the treatment conditions are established in a permit, are monitored for compliance, and the finished material has been tested to demonstrate that it meets all the applicable standards established under the more stringent of federal or state regulations. Vermont regulations, at §1-922 of the Vermont Wastewater System and Potable Water Supply Rules, do provide a minor exception for the disposal of composting toilet waste that is intended to mimic the landfill disposal provisions of Part 257, by providing for on-site disposal of the material:

> *§1-922 Composting or Incinerating Toilets and Greywater Disposal Systems*
>
> *(a) Composting or incinerating toilets may be approved in place of conventional water carried toilets. Use of these toilets in buildings other than single family residences on their own individual lots, is subject to review related to the adequacy of the particular unit for the proposed use.*
>
> *(b) All waste removed from a composting toilet shall be considered to be pathogenic. The waste material shall be disposed of at a certified landfill, or by shallow burial in a location approved by the Agency that meets the minimum site conditions given in section 1-805 of these Rules.*

Even if the manufacturers of these alternative systems were to obtain a PFRP equivalency determination from the PEC, the unrestricted use of the "biosolids" they produce under any permitting authority would not be sufficiently protective of human health unless specific monitoring, testing, and reporting protocols were also established and required, as most of these innovative technologies require faithful on-going maintenance by their owner/operators in order to maintain and assure their proper function and capabilities to destroy pathogens. Alternatively, the wastes removed from composting toilets may only be disposed by bagging the material and disposing of it in a landfill or by disposal at a WWTF.

Emerging Contaminants in Biosolids

Wastewater treatment facilities are highly regulated under the CWA and other regulatory requirements. During the 1970s and 80s, source control and industrial wastewater pre-treatment programs, established by USEPA under 40 CFR Part 403, began to limit the discharge of industrial pollutants into municipal sewers, resulting in a reduction of trace elements in wastewater and, therefore, biosolids (WEF 2004).

The EPA conducted two surveys in 1982 ("40 City Study") and 1988 (National Sewage Sludge Survey), to identify contaminants in sludge and to develop information on the fate and effects of priority pollutants in wastewater treatment plants and sludge. This information was used in establishing the Part 503 Rules. Since the promulgation of the Part 503 Rules, studies by the EPA, Water Environment Research Foundation (WERF) and other agencies have concluded that the Part 503 Rules adequately protect human and environmental health when biosolids management practices established in the rule are followed. For example, a comprehensive National Academy of Sciences/National Research Council review of the Part 503 Rules in 1996, and again in 2002, concluded that biosolids use on food crops and feed crops presents "negligible risk" when conducted in accordance with federal regulations (NRC 1996). In 2003, after five years of study, including a non-EPA peer review, the EPA determined that dioxins present in biosolids do not pose a significant risk to human health or the environment and elected not to regulate dioxins in land

applied sludge (USEPA 2003), although Maine and New Hampshire have established their own state standards for dioxin in biosolids.

During the last decade, however, the technological progress in analytical methods has enabled the detection and quantification of a large number of compounds at very low, previously undetectable, concentrations that are ubiquitous in our environment and that may accumulate in sludge during wastewater treatment. As a result, the EPA conducted a Targeted National Sewage Sludge Survey (TNSSS), collecting samples at 74 randomly selected publicly operated treatment works (POTWs) from 35 states in 2006 and 2007, to obtain updated concentration values for some pollutants previously evaluated and to obtain information on whether certain contaminants of emerging concern (CECs) may be present in sludge and at what levels. The EPA analyzed sludge samples for 145 analytes and reported a wide spectrum of concentrations of polycyclic aromatic hydrocarbons (PAHs) and semi-volatiles at the part per billion (µg/kg) scale, flame retardants in the part per trillion (ng/kg) to part per million (mg/kg) range, pharmaceuticals in the part per billion to part per million range, and steroids and hormones in the part per billion to part per thousand (g/kg) range (USEPA 2009b).

Micro-pollutants are often referred to as "contaminants of emerging concern" because the risk to human health and the environment associated with their presence, frequency of occurrence, or source may not be completely known. Examples include pharmaceuticals and personal care products (PPCPs), endocrine disrupting compounds (EDCs) such as organohalogen and organophosphate flame retardants, plasticizers (bisphenol A, etc.), detergent metabolites (alkylphenols, etc.) and natural or synthetic steroids/hormones, as well as pesticides, disinfectants, antimicrobials and other organic contaminants that occur in trace levels in our environment and are commonly derived from consumer products discharged to municipal, agricultural, and industrial wastewater sources and pathways.

The large majority of CECs enter municipal wastewater through bathing, cleaning, laundry, and the disposal of human waste and unused pharmaceuticals (USEPA, 2010). The occurrence of CECs in sludge will depend on the concentration and physiochemical properties of contaminants in wastewater sources, on the extent of industrial wastewater pre-treatment, and on the operational conditions of the wastewater treatment facility. Although WWTFs are designed to reduce the load of organic pollutants and pathogens in treated wastewater discharged to the environment, WWTFs are not designed to specifically remove CECs from wastewater (USEPA 2009, 2010), nor are such contaminants currently regulated in wastewater effluent. Therefore, many organic contaminants enter and leave WWTFs unaltered or incompletely removed and subsequently enter surface waters (Kolpin et al. 2002, Kinney et al. 2006) like Lake Champlain (Phillips et al. 2009; 2012). The impact of CECs on aquatic ecosystems has been thoroughly examined and remains the focus of several recent studies (Blair et al. 2013, Rosi-Marshall et al. 2013, Bradley & Kolpin 2013). However, because WWTF influent is partitioned into two components by the treatment process, sludge and liquid effluent, a significant fraction of the total organic contaminants entering a WWTF could reside in sludge, and therefore, biosolids. A notable study by Heidler and Halden (2007) investigated the persistence of the antimicrobial, Triclosan, in a conventional activated sludge WWTF and concluded that the majority of the compound was partitioned to the solid phase and sequestered into the wastewater residuals. The authors also noted that estimations of aqueous-phase removal efficiencies for wastewater contaminants should not be interpreted as proof that these pollutants are actually being destroyed due to the mere transfer of a significant fraction of the contaminant mass to municipal sludge. Concerns over the effects of Triclosan in the environment and on human health have led the Minnesota legislature to ban the sale of retail consumer products containing Triclosan in that state commencing January 1, 2017.

Roccaro et al (2014) subjected a number of CECs to the risk assessment used by EPA in establishing the Part 503 standards. All CECs examined were limited by Pathway 5 (Biosolids>soil>animal>human). The results of Roccaro's work determined that that regulatory limits (RSC in Table 7), if enacted, would generally be several orders of magnitude greater than the maximum concentrations detected in multiple studies. Section 405 of the CWA would therefore prohibit EPA from establishing regulatory limits for the CECs evaluated because their highest expected concentration in biosolids is but a fraction of what the risk based limit would be set at. Regardless, Roccaro evaluated what is obviously a very limited set of CECs, and the simple fact that none of those evaluated would warrant regulatory limits under the CWA does not in any way suggest that a risk assessment on other CECs would produce similar results. Such an assessment should be performed on as many CECs as possible.

Table 7. RSC values and maximum observed concentrations of target PPCPs in biosolids

Contaminant	RSC (mg/kg, dw)	Max. Concentration (mg/kg, dw)
Chlortetracycline	11,919	0.043
Doxycycline	754	1.780
Erythromycin	120	0.183
Monensin	39	not determined
Oxytetracycline	7,957	0.005
Trimethoprim	520	0.133
Tilosyne	21,441	0.005
Carbamazapine	13	0.238
Fluoxetine	15	0.258
Triclosan	472	1.508

The EPA continues to conduct biennial reviews of the Part 503 standards for the purpose of regulating new pollutants that may be present in biosolids and to ensure that there are effective and protective management practices in place. However, currently there are no federal regulations requiring the testing of biosolids for the presence of organic chemicals. To help fill the gaps in knowledge regarding the presence of organic chemicals in sewage biosolids, a growing number of studies have focused on emerging contaminants in wastewater effluent and sludge. In 2006, for example, Harrison et al. published results from an extensive literature review of organic chemicals in sludge and reported data for 516 organic compounds grouped into 15 classes. The vast majorities of these chemicals were not on the EPA established list of priority pollutants or target compounds, demonstrating the need for additional surveys of organic chemical contaminants in sludge and, more importantly, to assess the potential risks from biosolids land application to human and environmental health through various pathways.

Neither Part 503 nor the VSWMR establish standards for radionuclides in biosolids. After concluding a study in 2004, the Sewage Sludge Subcommittee of the Interagency Steering Committee on Radiation Standards (ISCORS) issued its report on the occurrence and risks of radionuclides in sewage sludge and sludge incinerator bottom ash. The ISCORS Study report presented the following:

> *As a result of Congressional interest, the Sewage Sludge Subcommittee of the Interagency Committee on Radiation Standards (ISCORS) conducted a survey of radioactive material in sewage sludge and ash and performed dose modeling of the*

survey results to address these concerns and to estimate typical levels of radioactive materials in POTWs around the country.

The survey obtained sewage sludge and incinerator ash samples from 313 POTWs across the country. A total of 45 radionuclides were detected, with 8 radionuclides (Be-7, Bi-214, I-131, K-40, Pb-212, Pb-214, Ra-226, and Ra-228) reported in more than 200 samples. The highest concentrations were observed for I-131, Tl-201, and Sr-89 (all short half-lived medical isotopes). Many samples contained radium and uranium. The survey results represent a single sampling event at the 313 POTWs, and therefore, do not account for seasonal or episodic fluctuations in radionuclide levels. The POTWs participating in this survey were specifically selected for their potential for finding elevated levels of radioactive materials in their sewage sludge or ash.

Three overall conclusions that arose included the following: (1) Elevated levels of radioactive materials were found in some sewage sludge and ash samples, but did not indicate a wide-spread problem; (2) Estimated doses to potentially exposed individuals are generally well below levels requiring radiation protection actions; and (3) For limited POTW worker and onsite resident scenarios, doses above protective standards could occur. This was primarily due to indoor radon generated as a decay product of naturally occurring radionuclides, such as Ra-226 and Th-228.

Therefore, based on conservative assumptions, there are no cases where the 95th percentile dose exceeds the limit of total radiation exposure of 100 mrem per year to individual members of the general public from all controllable sources as recommended by international and national radiation protection advisory bodies (International Commission on Radiological Protection and National Council on Radiation Protection and Measurements). This conclusion suggests that doses from exposure to radionuclides in sewage sludge and ash are below the current limit of total radiation exposure, based on the ISCORS Survey and Dose Assessment.

Some basic information regarding the sources, uses, and half-lives of common radionuclides are presented in Appendix 5: Table A-7.

Most recently, in 2016 a prime example of the issues surrounding CEC contamination of biosolids arose which highlights the uncertainties CECs bring to biosolids management. Perfluorooctanoic acid (PFOA) and perfluorooctane sulfonic acid (PFOS) are two CECs that were used extensively in the manufacture of Teflon coatings, commercial products that resist heat and chemical reactions, stain-resistant carpets and fabrics, water repellant clothing, paper and cardboard food packaging, and in fire-fighting foams. They are extremely persistent in the environment and are resistant to typical environmental degradation processes. As a result, they are widely distributed across the higher trophic levels and are found in soil, air and groundwater at sites across the United States (and around the world). The toxicity, mobility and bioaccumulative potential of PFOA and PFOS pose potential adverse effects for the environment and human health.

PFOA and PFOS do not break down easily, and therefore they persist for a very long time in the environment, especially in water. PFOA's half-life in water is estimated to be greater than 92 years and in the atmosphere at approximately 90 days, and the estimates for PFOS are greater than 41 years and

approximately 114 days respectively (EPA 2014). Its toxicity and persistence in the environment means it is a potential danger to human health and the environment.

PFOA levels in blood are related to increased lipids, uric acid and liver enzymes in the blood, which may or may not lead to effects on an individual's cardiovascular system, kidneys or liver. Studies have also shown a correlation, but not a cause-and-effect relationship, between levels of PFOA in the blood and high blood pressure, decreased birth weight, some immune system effects, thyroid disease, kidney cancer and testicular cancer (VDOH 2016). PFOA is classified as "likely to be carcinogenic in humans" by the EPA's Science Advisory Board.

The Department's investigation into the issues surrounding groundwater contamination (and hence numerous private drinking water sources) with PFOA, PFOS, and their associated analogs in a number of Vermont communities has revealed that in some cases the sludge produced by the WWTFs serving the contaminated areas is also contaminated with those compounds. It is probable that the contaminants are introduced to the WWTF through the infiltration of contaminated groundwater into sewage collection systems and through the treatment of septage generated at homes in areas where the groundwater (and hence their water supply) is similarly contaminated. In particular to this case, sludge from the Town of Bennington's WWTF (the Town is the locus of the worst contamination in Vermont) has for more than 25 years been composted to EQ standards and distributed to the public for general use. Historically, the composting was conducted in a unit located at the Town's WWTF and the finished product was marketed and distributed by a third party vendor both in and outside of Vermont. Following the closure of that facility, Bennington sludge has been shipped to another biosolids compost facility at the WWTF in Williamstown, MA, where it is also ultimately distributed to the public for general use after being treated to EQ standards.

The concerns over PFOA in biosolids are most closely related to the potential for PFOA leaching out of land applied biosolids and subsequently contaminating groundwater. Studies have shown that PFOA will readily leach out of biosolids and soils as it is relatively soluble in water (9.5 g/L) and does not bind to organic matter in biosolids or soils. While research demonstrates that dermal absorption of PFOA is minimal and its volatility is fairly low, meaning that mere skin contact with PFOA contaminated biosolids presents minimal risk and the likelihood of excessive exposure via inhalation is also minimal; exposure from drinking contaminated water or from the ingestion of contaminated materials does present significant potential health risks in direct proportion to the amount of PFOA ingested. The Department has recently proposed establishing new groundwater protection standards for PFOA and PFOS in the Vermont Groundwater Protection Rule and Strategy by setting a Preventive Action Limit of 0.1 ppb and an Enforcement Standard of 0.2 ppb, and has proposed establishing liquid wastes containing PFOA and/or PFOS in concentrations greater than 20 ppt (total) as Vermont listed hazardous wastes in the Vermont Hazardous Waste Management Regulations. VDOH has also issued a Drinking Water Health Advisory for PFOA and PFOS, which establishes that water having a total PFOA/PFOS concentration of 20 ppt or greater should not be consumed, that is lower than EPA's recommendation of 70 ppt total PFOA/PFOS.

Although a "typical" single application of PFOA contaminated biosolids (4 dry tons/acre at 50 ppt PFOA and incorporated into the plow layer – typically estimated at 2 million pounds of soil per acre) will result in an increase in the soil PFOA concentration of 0.2 ppt, the entire mass of PFOA applied is susceptible to leaching to groundwater. The Department's investigations into the implications of this matter is an on-going effort and is an excellent example of the challenges that CECs pose to biosolids management.

Transport and Fate of Biosolids Bourn CECs in the Environment

CEC exposure pathways from the land application of biosolids, as reported in the literature, include direct soil consumption by foraging livestock (Fries 1996, Wild et al. 1994), uptake of contaminants into plants consumed by livestock (Wild et al. 1994, Rideout & Teschke 2004, Macherius et al. 2012) and humans (Kipper et al. 2010, Karnjanapiboonwong et al. 2011, Sauborin et al. 2012, Wu et al. 2012), terrestrial bioaccumulation (Kinney et al. 2008, Snyder et al. 2011, 2013), leaching and/or runoff from land applied fields to surface and ground waters (Lapen et al. 2008, Gottschall et al. 2012, 2013, Wong et al. 2012, Yang et al. 2012) and bioaerosol transport from land application operations (Rusin et al. 2003, Pepper et al. 2008, Viau et al. 2011).

The occurrence of organic chemicals in soil and the potential transfer of contaminants through various pathways depend on many factors, including the concentration and physiochemical properties of contaminants in amendment source, soil type, organic matter, reduction/oxidation (redox) potential, pH, the pollutant's octanol/water partition coefficient, slope of fields, presence and type of vegetation, rate and method of application, management practices, and climate parameters affecting degradation and off site transport such as temperature and precipitation.

Generally, organic contaminants that survive wastewater treatment are strongly bound to organic matter in biosolids amended soils and are relatively insoluble in water, thus limiting their leaching potential. Gottschall et al. (2012, 2013) reported no significant impact on the quality of either tile drainage or groundwater despite very high rates of biosolids application (~9.8 dry tons/acre) and detection of PPCPs in biosolids aggregates up to one year post-application. The authors reported several mechanisms that limited tile and groundwater contamination, including incorporation of biosolids via tillage, lighter textured soils with fewer macropores, a deep tile drainage system, and limited winter precipitation. However, the same group of researchers (Lapen et al. 2008, Edwards et al. 2009) published very different results from a similar experiment that monitored PPCPs in tile drainage post application of biosolids. Lapen et al. (2008) showed that PPCPs moved rapidly to tile drains via soil macropores and were found in maximum concentrations of 10 to 1000 parts per trillion (ng/L). The conflicting results between these studies are most likely attributed to different experimental conditions, namely in Lapen et al. (2008): i) the selected PPCPs were spiked into biosolids; ii) biosolids were liquid with very low solids content; iii) soil type was more clayey with macropores (worm burrows) and; iv) the fall application season was wet with frequent and heavy rainfall. In fact, Lapen et al (2008) admits that the conditions of their study represented a 'worst case' scenario in terms of contamination risk from tile drainage.

As with any fertilizer, attention to weather conditions, to application rates and to appropriate management practices are important for reducing losses of nutrients (particularly phosphorus) and other compounds through runoff or over-application (Pepper et al. 2008). Positive correlations have been reported for rainfall and hormone runoff from agricultural test plots amended with biosolids, but those studies were conducted under simulated conditions of heavy precipitation replicating 100-year rainfall events 5 days before and 1, 8 and 35 days after biosolids application (Yang et al. 2012). A study of viral contaminant runoff from biosolids amended fields by Wong et al. (2010) also used a simulated rainfall rate that was much higher than natural rainfall rates. Results demonstrated that sandy-loam soils with a vegetative cover can be an effective filter for removing viruses due to virus sorption to biosolids particles and that the depth of the soil profile was an important factor. However, because high rainfall rates saturated the soils and created surface ponding, water samples from ponded water contained viral contamination that, according to the authors, represented a threat to water quality when biosolids were allowed to remain on the soil surface after application. The authors suggest using management practices to reduce runoff

potential, including pre-tillage, low application rates, incorporation or injection, and timing of application to avoid wet ground or significant rainfall.

As presented in the "Biosolids Regulation: Federal and Vermont" section of this document, Vermont's regulations address the potential runoff exposure pathway via several mechanisms. Application practices and rates for biosolids and septage are strictly controlled and application of biosolids to frozen or snow covered ground, or where there is less than 36" of unsaturated soil, is prohibited. Furthermore, minimum isolation distances (Table 6) and site monitoring requirements (Table 5) for land application exceed corresponding federal standards or are established where no federal standards exist.

In addition to research on the potential for runoff of organic chemicals from amended agricultural lands, the uptake of emerging contaminants to vegetation from amended soils has been a topic addressed by numerous research studies. Manure from livestock and poultry is a source of a number of contaminants, including pathogens, hormones, pharmaceuticals, and antimicrobials; and several studies have documented the presence of veterinary medicines in manure amended soils (Kumar et al. 2005, Boxall and Johnson 2006, Dolliver et al. 2007, Bassil et al. 2013). In 2007, the approximately 2.2 billion livestock in the U.S. generated an estimated 1.1 billion tons of manure (USDA 2009), which the EPA estimated to be an amount 13 times greater than all human sewage sludge produced in the U.S. (USEPA 2013). Vermont farms produce and manage an estimated 3.8 million tons of manure annually and ranks #3 out of all U.S. states in the amount of manure generated on a farmland area basis, with an estimated 3.05 tons of manure per acre (USEPA 2013). Almost 34 million pounds of antimicrobials were sold for livestock in 2014 in the U.S. (FDA 2015), an estimated four to five times greater than the amount used to treat human infections (USEPA 2015). The uptake and accumulation of such chemicals into plants is well documented, however, authors report mixed conclusions regarding risks to human health. Kumar et al (2005) found that the uptake of the antibiotic, chlortetracycline, into plant tissues was small (2-17 ng/g fresh weight) but concluded that there were potential human health risks associated with consumption of fresh vegetables grown in soil amended with antibiotic laden manures. Similarly, Dolliver et al (2007) demonstrated the uptake of the veterinary antibiotic sulfamethazine into corn, lettuce and potato plant tissue, with concentrations ranging from 0.1 to 1.2 mg/kg (dry weight). Although less than 0.1% of applied sulfamethazine accumulated in plant tissue after 45 d of growth, and greater than 70% remained in soil, results raised potential human health concerns of consuming low levels of antibiotics from produce grown on manure-amended soils. Bassil et al (2013) performed a pot study in the greenhouse to measure the uptake of gentamicin and streptomycin by carrot, lettuce and radish, reporting that these plants did not absorb either antibiotic in significant quantities except for the uptake of gentamicin into radish root. All three studies (Kumar et al. 2005, Dolliver et al. 2007, and Bassil et al. 2013) found that levels of antibiotics in plant tissue increased with increasing concentration in manure. Boxall and Johnson (2006) also used pot studies with manure amended soils to study uptake of veterinary medicines into carrot roots (tubers) and lettuce leaves. Although exposure concentrations were appreciable in a few instances, accounting for 10% of the acceptable daily intake values (ADI), all were lower than the ADI values, indicating little evidence of an appreciable risk.

Approximately 6300 wet tons of Class B biosolids were land applied to about 0.06% of Vermont's agricultural land in 2015 (Appendix 3: Table A-5) and nationally, biosolids are applied to approximately 0.1% of agricultural land (NRC 2002). Yet much of the research on potential pathways of emerging contaminant into the food chain has focused on uptake and accumulation of pollutants into plants grown on biosolids amended fields. Several of these recent studies are summarized in Table 8.

Table 8. Literature review of recent studies of plant uptake of emerging contaminants.

Conditions	Contaminant	Vegetation	Author Conclusions	Author/Year
Hydroponics, spiked test compounds	bisphenol A, diclofenac, naproxen, 4-nonylphenol	Lettuce, collards	Accumulation (µg/kg) greatest in roots, human dietary uptake predicted to be negligible	Dodgen et al. 2013
Hydroponics, spiked test compounds	carbamazepine, salbutamol, sulfamethoxazole, trimethoprim	Cabbage, Wisconsin Fast Plants (B*rassica rapa*)	Human pharmaceuticals can be actively taken up by plants (µg/kg) under hydroponic conditions	Heklotz et al. 2010
Soil pots, spiked test compounds	organophosphates, plasticizer & insect repellant (DEET)	Barley, wheat, meadow fescue, oilseed rape, carrot	High translocation into leaves of meadow fescue (mg/kg), a forage crop. Risk assessment needed	Eggen et al. 2013
Soil pots, spiked test compounds	carbamazepine, salbutamol, triclosan, sulfamethoxazole, trimethoprim	Chinese cabbage	PPCPs at environmentally relevant concentrations resulted in uptake and plant accumulation (µg/kg)	Holling et al. 2012
Soil pots, spiked test compounds	17α-ethynylestradiol, triclosan	Bean plants	Uptake and accumulation (mg/kg) greater in plants grown in sand vs clay soil	Karnjanapiboonwong et al. 2011
Soil pots, spiked test compounds	fluroquinolines and sulfonamides	Potato	Uptake into potato (µg/kg) and low adsorption of on soil may contaminate food plants	Kipper et al. 2010
Soil pots, spiked test compounds	Sulfonamides	Pakchoi Cabbage	Uptake into cabbage (µg/kg); microbial degradation in soil mechanism of dissipation	Li et al. 2013
Soil pots, spiked test compounds	galoxlide, tonalide, triclosan	Carrot, Barley, Meadow Fescue	Accumulation (mg/kg) in carrot peel relevant to food chain; intro to food chain via feeding livestock less likely due to low uptake to aerial plant parts	Macherius et al. 2012
Soil pots, spiked test compounds	Triclosan (TCS)	Lettuce, radish, bahia grass	TCS may accumulate (mg/kg) in plants; no toxicity at agronomic application rates	Pannu et al. 2012
Soil pots, spiked test compounds; model simulations	Organophosphates, plasticizer & insect repellant (DEET)	Barley, carrot	Organophosphates have a high potential for bioaccumulation (mg/kg) in crops; reach agricultural fields via biosolids and by atmospheric deposition	Trapp & Eggen 2013
Soil pots, spiked test compounds	Carbamazepine, diphenhydramine, fluoxetine, triclosan, triclocarb	Soybean	Uptake of PPCPs (µg/kg) into edible portion of agriculturally important crop; uptake behavior compound specific	Wu et al. 2010
Soil pots, biosolids amended	triclocarban (TCC), triclosan (TCS)	Pumpkin, zucchini, switch grass	Leaves and stems accumulated (mg/kg) TCC and TCS; plant uptake reduced leaching	Aryal & Reinhold 2011

Soil pots, biosolids application	4-nonylphenol	Wheat, oil seed rape	Rapidly degraded in soil; biosolids enhanced mineralization; low rate of uptake into plant	Roberts et al. 2006
Soil pots, sludge amended	ketoprofen, naproxen, diclofenac, ibuprofen	Wheat, soybean	No detectable uptake even at 2x sludge application rate. Risk of exposure via crops very small.	Cortes et al. 2013
Soil pots, biosolids amended, spiked test compounds	Carbamazepine, diphenhydramine, triclocarb	Pepper, tomato, collard, lettuce, radish	PPCP uptake and accumulation (µg/kg) into plant tissue affected by PPCP physio-chemical properties and interaction with soil	Wu et al. 2012
Field study, biosolids application	Pharmaceuticals and personal care products (PPCPs)	Wheat	No PPCPs detected in wheat grain planted post, high rate biosolids application; no significant impact on quality of tile drainage or groundwater	Gottschall et al. 2012
Field study, biosolids application	PBDEs (flame retardants)	Corn	PBDE soil concentrations increased but corn did not exhibit measurable uptake	Hale et al. 2012
Field study, biosolids application	Pharmaceuticals, hormones, parabens	Tomatoes, carrots, potatoes, sweet corn	Little risk of PPCP uptake into vegetable crops with one year offset between biosolids application and harvest	Sauborin et al. 2012

The studies referenced in Table 8 confirm the potential for plants to uptake and accumulate a variety of emerging contaminants in concentrations ranging from parts per billion (µg/kg) to parts per million (mg/kg, dry weight). However, the results and conclusions from the majority of these studies are the outcome of experimental methods that do not reflect actual field conditions and, therefore, must be considered in that context. For example, studies employing hydroponic cultivation (Dodgen et al. 2013, Heklotz et al. 2010) neglect the contaminant-soil and plant-soil interactions that greatly impact contaminant availability to plant uptake. Macherius et al (2012) noted that the use of hydroponic cultivation likely resulted in greater plant accumulation of PPCPs/EDCs due to the absence of chemical sorption to soil organic matter and minerals. It should also be realized that there is absolutely no use for biosolids or biosolids amended soils in hydroponic agriculture, as all required nutrients are supplied by the hydroponic solution and hydroponic systems do not use soil as the growing media, rendering studies of chemical uptake into hydroponic crops suspect as to their applicability to biosolids management in conventional agriculture.

Similarly, the majority of the studies above relied on laboratory growing conditions (pot studies) with soils spiked with test compounds as opposed to amending soils with biosolids that contain pollutants of concern (Eggen et al. 2013, Holling et al. 2012, Karnjanapiboonwong et al. 2011, Kipper et al. 2010, Li et al. 2013, Macherius et al. 2012, Pannu et al. 2012, Trapp & Eggen 2013, Wu et al. 2010). Pannu et al. (2013) warned that using models, empirical equations, hydroponics, and unamended systems overestimate the bioaccumulation potential of the antimicrobial Triclosan, and may not be applicable for biosolids-amended soils.

More appropriate than studies employing hydroponics or soil pots with spiked test compounds are experiments that use soil pots but amend the soils with biosolids (Aryal and Reinhold 2011, Roberts et al. 2006, Cortes et al. 2013, Wu et al. 2012). However, such studies fail to take into account the variations in field conditions when assessing persistence of compounds and potential risks. Chaney et al (1999) warned of the tendency for overestimation of metal uptake by plants when extrapolating from pot studies in the greenhouse to the field. Langdon et al (2012) concluded that using experiments to predict field persistence of compounds in biosolids amended soils may overestimate degradation rates and inaccurately predict patterns of dissipation, although their findings were likely due to the unfavorable environmental conditions for degradation at the location of the field trial. Similarly, Holling et al. (2012) noted that in most studies, uptake of PPCPs has been evaluated under non-standard growing conditions or at concentrations of PPCPs that are elevated relative to those expected in soils amended with agronomic rates of biosolids. It is important to understand the potential uptake of contaminants by crops exposed to environmentally relevant concentrations.

Only three of the studies referenced in Table 8 were performed under actual field conditions where soils were amended with biosolids (Gottschall et al. 2012, Hale et al. 2012, Sauborin et al. 2012). These studies generally demonstrated low risk to human health from biosolids borne PPCPs, PBDEs, hormones and parabens, citing low rates of plant uptake and minimal impact on ground water quality. Even under conditions where vegetables of the family Cucurbitaceae (zucchini, pumpkin) were shown to accumulate antimicrobials Triclosan and Triclocarb in mg/kg concentrations in leaves and stems when grown in biosolids amended soils, the predicted acute risk from direct human consumption was considered minimal (Aryal & Reinhold, 2011). However, it is important to note that these studies represent only a portion of the potential research on plant uptake of contaminants from biosolids amended soils. It is also important to note that more data has been collected for certain chemical classes than for others that may pose greater risk. Metabolites of some compounds can also be of environmental concern and may be converted back to the parent compound once the metabolites reach the environment (Jjemba et al. 2002). Therefore, a disregard of conjugates in studies on plant uptake of environmental contaminants may severely underestimate the extent of uptake into plants and, eventually, the potential human exposure to contaminants via food of plant origin (Macherius et al. 2012).

Another contaminant exposure pathway associated with biosolids land application is through crop uptake and bioaccumulation into livestock. In 2004, Rideout & Teschke reported results from a literature review of the potential for increased foodborne exposure to polychlorinated dioxins and furans (PCDD/F), rather than potential health outcomes, when sludge is used on agricultural land. The authors reported a weak correlation between concentrations in soils and concentrations in root crops, leafy vegetables, tree fruits, hay and herbs, and that in all cases, large increases in PCDD/F soil concentrations were required to achieve a measurable increase in plant contamination. These results suggest that biosolids application to land used for most crops would not increase human exposure. However, a considerably stronger positive relationship was observed between PCDD/F in feed and resulting levels in cattle tissue, suggesting bioaccumulation. Although PCDD/Fs are excreted in milk, no association was found between feed contamination and levels of PCDD/Fs measured in milk. Still, the use of sludge on land used to graze domestic food source animals appears likely to result in increased human exposure to PCDD/F.

Grazing animals may be exposed to contaminants by consuming soil along with fodder; either by eating soil directly or by consuming plants to which soil has adhered (Chaney et al. 1996). Wild et al. (1994) pointed to the key role of PCDD/F transfer into livestock via ingestion of biosolids adhered to vegetation. Fries (1996) reported that cattle may consume an average of 6% of their ingested dry matter as soil but that soil ingestion by lactating dairy cows would likely not exceed 1-2% under normal management conditions. Fortunately, Vermont's regulations address this exposure pathway by prohibiting the grazing

of domestic food source animals on biosolids amended sites for a minimum of six months following the last application event.

When biosolids are applied to fields in accordance with such site use restrictions and with pollutant loading limits, risk to human health and the environmental from synthetic organic compounds is minimized by a number of barriers. Chief among these is the fact that organic compounds that survive wastewater treatment are strongly bound to organic matter in soils and are relatively insoluble in water. For example, PBDEs are strongly sorbed to soil colloids and are relatively immobile in soil, potentially (depending on its degradation rate) remaining conserved in soils for decades or longer (Pepper et al. 2008). More recently, Yager et al. (2014) reported dissipation of CECs in land applied biosolids during weathering at the soil surface by vertical transport into the soil column, but results also showed long-term (> 1 year) storage of persistent CECs in surface soils. Limited mobility of biosolids bound CECs, along with site management practices such as buffer zones, incorporation/tillage and restrictions on application timing; reduce the opportunity for these compounds to move to water bodies. Furthermore, compared with aquatic ecosystems, terrestrial systems have orders of magnitude greater microbial capability and residence times to achieve decomposition and assimilation (Overcash et al. 2005). Lorenzen et al. (2006) reported that endocrine disrupting compounds in biosolids rapidly degrade following land application and, similarly, Roberts et al. 2006 showed rapid mineralization of the surfactant metabolite 4-nonylphenol in soils under aerobic conditions.

It has become generally accepted that only field data from long term studies of environmental contamination sources provide data appropriate for risk assessment and environmental regulation (Chaney et al. 1999). Research has indicated drastic differences in the rate of decomposition of organic compounds between studies examining decomposition rates in biosolids amended field soils and laboratory pot tests. Degradation rate differences are generally attributed to the variations in field conditions present in natural field settings versus what is experienced in laboratory tests. Overcash & Pal (1979), Clark & Smith (2011), Langdon et al. (2012), and Gottschall et al. (2012) have reported the observed half-lives of a number of organic contaminants in biosolids amended field soils (Table 9).

Table 9. Half-life (days) of selected organic compounds in biosolids amended soil systems.

Compound	Half-life (days)	Researcher
hydroquinone	0.5	Overcash & Pal 1979
pyrocatechin	0.5	Overcash & Pal 1979
testosterone	0.5 – 8	Overcash & Pal 1979
17β-estradiol	1 – 10	Overcash & Pal 1979
phenol	1.3	Overcash & Pal 1979
2,4-methylaniline	1.5	Overcash & Pal 1979
polydimethylsiloxanes	2 – 28	Overcash & Pal 1979
17β-ethanyl estradiol	3 – 10	Overcash & Pal 1979
acetic acid	5 – 8	Overcash & Pal 1979
ibuprofen	12	Clark & Smith 2011
quaternary ammonium compounds	17 – 40	Clark & Smith 2011
Gemfibrozil	20	Clark & Smith 2011
cellulose	35	Overcash & Pal 1979
octylphenol	35	Overcash & Pal 1979
n-nitrosodiethylamine	40	Overcash & Pal 1979
bisphenol A	43	Langdon et al. 2012

carbamazepine	46	Gottschall et al. 2012
acetaminophen	63	Gottschall et al. 2012
organotin compounds	70	Clark & Smith 2011
azithromycin	71	Gottschall et al. 2012
4-t-octylphenol	75	Overcash & Pal 1979
nonylphenol	80	Overcash & Pal 1979
di-n-butyl phthalate ester	80 – 180	Overcash & Pal 1979
anthracene	110 - 180	Overcash & Pal 1979
synthetic musk compounds	180	Clark & Smith 2011
Galaxolide	180	Clark & Smith 2011
triclosan	182	Gottschall et al. 2012
epitetracycline	198	Gottschall et al. 2012
Ofloxacin	198	Gottschall et al. 2012
Norfloxacin	289	Gottschall et al. 2012
miconazole	347	Gottschall et al. 2012
benzo (a) pyrene	60 - 420	Overcash & Pal 1979
non-ionic surfactants	300 - 600	Overcash & Pal 1979
aminoanthroquinone dye	100 - 2000	Overcash & Pal 1979
polydimethylsilicone	900 - 1400	Overcash & Pal 1979
polybrominated diphenyl ethers (PBDE)	1400 – 7300	Clark & Smith 2011

As is evidenced by these data, many CECs are degraded relatively quickly in agricultural soils. With the exception of polyhalogenated diphenyl ethers, biphenyls, dioxins, and similar highly stable molecules; the half-life of most of these compounds is on the order of six months or less. These compounds are all relatively resistant to decomposition in the chemical and biological conditions of the wastewater treatment environment but all exhibit accelerated degradation rates in soil systems. This is due in large part to the differences in the chemical and environmental conditions that these compounds are exposed to in the two environments. Chemicals which "survive" wastewater treatment, when placed into an agricultural soil media, are exposed to a wide range of new biological and chemical reactions that they were not exposed to in the wastewater treatment process. Additional chemical degradation processes to which these compounds are exposed includes hydrolysis reactions, photolytic reactions, adduct formation, redox reactions, acid/base neutralization, and precipitation, among others. *In situ* agricultural soils also contain populations of a huge variety of aerobic bacteria and other higher organisms that are not present in wastewater treatment operations. These naturally occurring organisms are typically present in densities that are many orders of magnitude greater than those found in wastewater treatment processes, and they provide numerous additional routes of metabolic decomposition compared to those provided by microbial activity during wastewater treatment.

In general, chemical concentrations and the risk of exposure to contaminants via biosolids is very low in comparison to other routes of exposure. For example, human exposure to flame retardant chemicals is greatest from household dust (Lorber 2008), and exposure from consumption of vegetables known to accumulate antimicrobials when grown in biosolids amended soils is substantially less than from use of the product in which they were originally contained (Aryal & Reinhold 2011). Furthermore, recent risk assessments published in the American Society of Microbiology's (2011) report on "Land Application of Organic Residuals" indicate that the spread of human pathogens via biosolids show lower human health risk for many microbial contaminants in municipal biosolids than for manures. However, before biosolids application, careful consideration should be given to the types of agricultural products grown and to the optimization of site management practices that limit exposure. Allowing as much time as practicable between biosolids applications allows for maximum degradation and assimilation of

contaminants and the least potential for long term disruption of the soil ecosystem. In addition, biosolids managers should support pollution prevention and other source control programs that promote the disposal of PPCPs and pharmaceuticals by means other than wastewater. WWTF personnel should maximize the potential for biological degradation of organic contaminants by prolonging detention times (Leu et al. 2012) and by using various treatment methods (anaerobic and/or aerobic digestions, composting). While most of these compounds could potentially be destroyed or removed from sludge by using technologies such as ozonation or activated carbon filtration (both very expensive from a capitol and operating cost perspective), serious consideration must be given to the appropriateness of the use of these "contaminants" in the consumer products from which they originate.

The Vermont legislature lent serious credence to this position via the passing of Act 188 in the 2014 legislative session, which enumerated a list of 66 chemicals (actually more, as the list includes eight entries such as *"Cadmium and cadmium compounds"*, all of which can include hundreds of individual chemicals) that are considered hazardous to children. However, the listed contaminants are toxic to adults just as they are to children; and either do, or have the potential to create toxic effects on other organisms when released into the environment.

Currently, there a number of efforts under way to develop a reliable, repeatable, and scientifically sound method (a Quantitative Microbial Risk Assessment) of directly measuring the impact of biosolids, or more accurately the contaminants they contain, on the health and fertility of agricultural soils. In general, these efforts are centered on the development of a bioassay method that could be used in real time and in *in situ* applications as a compliance tool. While there is no disputing the presence of numerous contaminants in biosolids, the ultimate consideration of policy decisions cannot be based on mere presence. Fortunately, this is one area of research in which EPA has continued to invest funding. Staff at EPA's research facility in Cincinnati, in cooperation with the PEC, have made significant strides in developing a bioassay method that is applicable to biosolids management. Although a final method is still unlikely to be fully developed, tested, and vetted for a number of years; care must be taken to not adopt currently available screening methods which are wholly inapplicable to measuring the impacts of land applying biosolids. For example, recent research on a soil screening method developed at Duke University serves well to emphasize the need to critically review any claims of a particular method's applicability. In a paper titled "*Determining the Ecological Impacts of Organic Contaminants in Biosolids Using a High-Throughput Colorimetric Denitrification Assay: A Case Study with Antimicrobial Agents",* Holzem et al. (2014) claimed to have modeled the ecological impacts of a few organic contaminants that are often found in biosolids. But the contaminants tested were not "in biosolids" when they were tested and no biosolids or soil was used in the assay. Rather, the researchers used bacterial cultures of "model denitrifiers" that were spiked with fresh samples of the chemicals being tested, a methodology that has repeatedly been shown as non-representative of actual biosolids amended soil characteristics. Conversely, research conducted at the University of California at Davis has tested the impacts on biosolids amended soils containing typical levels of the anti-microbials. That research found:

> *"that the increased N added with biosolids stimulates nitrogen cycling sufficiently to offset any detrimental impacts on the N cycling caused by Triclosan (TCS) at realistic application concentrations. Biosolids contain traces of TCS and other antimicrobials, but, because the chemicals become transformed and bound as they go through the wastewater and solids treatment processes, they are not as available as fresh chemicals added to soil, and their impacts are negligible. Meanwhile, the stimulating effects of the nutrients and organic matter in biosolids demonstrably boost soil microbial activity."*

The Program supports the development and use of a bioassay method that provides the reliability and assurances required of a demonstration of regulatory compliance.

The only alternative to the management of biosolids via land application or incineration currently available to Vermont WWTFs is disposal in a municipal solid waste landfill. As of this date, in August 2016, there is only one landfill operating in Vermont that is accepting biosolids for disposal – the Waste USA Landfill in Coventry, into which almost 30,000 wet tons (approximately 59,000 cubic yards) of sludge was disposed in 2015 alone. In 2015, approximately 17.5 million gallons of landfill leachate was disposed at three Vermont WWTFs (Barre, Montpelier, and Newport). Aside from the issue of consuming Vermont's very limited landfill capacity with a potentially reusable material, landfill disposal inevitably results in compounding the contentious issues surrounding the management of biosolids due to its impacts on pollutants in landfill leachate. Appendix 2 of this paper presents four tables of analytical data for contaminants in landfill leachates as a typical example. As is evident from Appendix 2: Tables A-1 through A-3, there is a wide range of contaminant types and concentrations present in landfill leachate, and it must be assumed that there are numerous other contaminants for which an analysis was not, or could not, be conducted. Albeit that a significant number of contaminants that were not included in these analytical efforts are relatively innocuous byproducts of the decomposition of other landfilled organic wastes that are extremely amenable to near complete degradation in wastewater treatment processes, Appendix 2: Table A-4 clearly shows that there are numerous compounds found in leachate that are structurally similar to CECs found in sludge and for which landfilled sludge would be one of the primary sources for leachate contamination. These compounds do not undergo degradation in a landfill's anaerobic reducing environment, just as they survived degradation in the wastewater treatment process, indicating that for many classes of chemicals, their leachate concentrations remain the same or may even increase over long periods of time. And, because all landfill leachate generated in Vermont is disposed for treatment at municipal WWTFs that manage their sludge production by landfilling it in the same facilities that generated the leachate, a closed loop is created wherein the mass loading and subsequent leachate concentration of these compounds can significantly increase over time. While this may appear to be a means of containing these contaminants in a closed system, it must be realized that the concentration of these contaminants in leachate will simply continue to rise and that there will be a commensurate decrease in the ability of the WWTF to remove them. This will inevitably result in a significant increase in the concentration of the contaminants in effluent discharged to surface waters and in the attendant issues that raises with aquatic biota that receive chronic low level exposure. For an in-depth analysis of the severe adverse effects on aquatic biota from chronic low level exposure to these contaminants, there is a wealth of research reports available through the U.S. Geological Survey's library catalog.

The continual cycling of leachate to sludge to leachate, along with the contaminants they contain, is likely not sustainable in the long term and may create a significantly larger and costlier problem for future generations of Vermonters to assume. The constant recycling of previously disposed contaminants and the on-going addition of new contaminants will only result in their ever increasing concentrations in the leachate and sludge. Ultimately, the liner and collection system of any landfill will fail, albeit that is highly unlikely to occur within the foreseeable future. Regardless of the timing, any such failure has the potential to result in the release of copious quantities of leachate and the contaminants it contains to the groundwater. Secondly, as sewage and septage inputs to municipal WWTFs continue to increase towards their design capacities for either flow or biochemical oxygen demand (BOD) removal, WWTFs will have a correspondingly decreasing capacity to accept and treat leachate. Eventually, this will require either upgrades to WWTFs in order to accept the increasing volumes of total flow (at a huge expense to the municipality, not the generator of the leachate) or increasing transportation distances to WWTFs with adequate capacity to accept the volumes of leachate being generated. In order to mitigate this concern, landfills permitted to operate in Vermont could be required to install and operate a private WWTF to

pretreat or fully treat leachate on-site to decrease the BOD concentration, and could also employ a process (akin to carbon filtration or ozonation) to efficiently remove or destroy the large majority of the organic contaminants of emerging concern discussed in this paper that pass through a WWTF, which is primarily designed for the treatment of pathogenic sanitary wastes, without degradation.

Emerging Concerns for Pathogens

Most land application occurs with class B biosolids that, by definition, are likely to contain human pathogenic bacteria, viruses, and protozoan parasites (see pages 17 - 18). A comparison of pathogen levels found within biosolids sampled before and after the Part 503 Rule has illustrated that the Part 503 Rule has been effective in reducing public exposure to pathogens relative to before the promulgation of the Part 503 Rules (Pepper et al. 2010). However, the Part 503 regulations pertaining to human exposure to pathogens were established through treatment-based standards and through land application guidelines rather than through risk or epidemiological analysis. And although the USEPA continues to support the Pathogen Equivalency Committee, which approves alternative sludge disinfection processes, potential exposure to pathogens from the land application of biosolids has called into question the sustainability of the practice of land applying class B biosolids.

The greatest amount of uncertainty in quantitative microbial risk assessment is due to a lack of data on exposure and proper assessments of risk from land applied biosolids, particularly for indirect routes of exposure, such as contact with bioaerosols at land application sites or consumption of groundwater that has passed beneath sites (Pepper et al. 2008, 2010). In addition, concerns have arisen about the presence of specific 'emerging pathogens' that could be present in biosolids. An emerging pathogen can be considered any pathogen that increases the incidence of an epidemic outbreak and examples include *Cryptosporidium*, *E coli* O157:H7, Hantavirus, multidrug resistant pneumococci, and vancomycin-resistant enterococci.

To evaluate the sustainability of land application of class B biosolids, the University of Arizona undertook a study that collected and analyzed biosolids samples from a single WWTF over an eighteen-year period, from 1988-2006. In addition, the same researchers conducted a national study on the incidence of pathogens in anaerobically digested biosolids produced within WWTFs across the US between 2005 and 2008. These two studies therefore represent a large database on the incidence of pathogens in class B biosolids, including national and historic distributions, and have generated several publications on the presence of and potential exposure risks to pathogens associated with the land application of biosolids.

Pepper et al (2008) analyzed pathogen data collected during the University of Arizona study in an effort to identify potential biological hazards associated land application of class B biosolids. They reported that both direct risks and indirect exposures via bioaerosols or microbially contaminated groundwater to human health posed by pathogens in biosolids were low. Specifically, the authors reported that while raw sewage was a definitive source of *Staphylococcus aureus*, the organism was never detected in Class A or B biosolids or in bioaerosols resulting from land application sites. These results agreed with previous work by Rusin et al. (2003) who showed that biosolids are not a significant source of *S. aureus* exposures or infections in humans. Community risk of infection from *Salmonella* and *Coxsackie virus A21* were also determined to be low at various distances from land applied biosolids, likely due to dilution and natural attenuation of pathogens from environmental factors such as desiccation and ultraviolet light. Ultraviolet light, which acts by rapidly scrambling the organisms' genetic material – thereby rendering them

incapable of reproducing, is a particularly effective antimicrobial to the extent that is commonly employed as the final stage disinfectant of treated wastewater effluent. Occupational risks to biosolids workers were evaluated and found to be low, although higher than community risks due to enhanced duration of exposure and proximity to the site. The authors also concluded that the majority of aerosols, including endotoxins, captured during land application arose from soils sources rather than from biosolids.

The limited transport of pathogens via aerosols may also be due to the binding of organisms to biosolids particles, which would also reduce the potential for microbial contamination of ground water. Work at the University of Arizona showed that viruses are embedded and/or adsorbed to biosolids, likely restricting the mobility and transport of viruses through the soil and vadose zone. These findings are consistent with studies referenced in the previous section of this document (Gottschall et al. 2012, 2013; Wong et al. 2010) and, although Pepper et al. (2008) cites conflicting reports on the effect of organic matter on the transport of pathogens in soil, the authors ultimately concluded that microbial contamination of groundwater from land application of biosolids is unlikely. However, while pathogens absorbed to or embedded within land applied biosolids are less likely to be transported to groundwater, contamination of groundwater or nearby surface waters by microbial pathogens from on-site sewage treatment (septic) systems is always a potential risk to human health. Scandura and Sobsey (1997) studied the survival and transport of a model enterovirus and fecal coliform bacteria in four on-site wastewater treatment systems, reporting that systems with the coarsest (sand) soils and highest water tables (shallowest vadose zones) saw extensive ground water contamination by viruses and other wastewater constituents. Therefore, on-site wastewater treatment systems must be properly sited, designed, installed, operated, and maintained to ensure adequate long term performance in treating microbial pathogens, and other contaminants in sewage. Similar considerations must, therefore, be afforded for siting land application projects.

The prevalence of antibiotic-resistant bacteria and endotoxins in soil after land application of biosolids was reported by Brooks et al. (2007) and reviewed by Pepper et al. (2008). Soil samples were collected before and for a 15-month period following land application of biosolids and soil bacterial resistance to ampicillin, cephalothin, ciprofloxacin and tetracycline was ascertained, all showing negligible increases in the percentage of antibiotic resistance bacteria. Similarly, no significant increases in the concentrations of endotoxins in soil were observed.

Additional research conducted at the University of Arizona on potential biological hazards associated with biosolids focused on the regrowth potential of *Salmonella* in both Class A and B biosolids and biosolids amended soil. Pepper et al. (2008) reported regrowth of *Salmonella* following rainfall events during which biosolids became saturated and anaerobic and specified that moisture content greater than 20% was required for regrowth. No regrowth occurred from Class A or B biosolids when the material was added to soil, regardless of saturation. The risks of infection from *Salmonella* in land applied Class B biosolids were low regardless of exposure route (ingestion or inhalation of aerosol), however, risks from ingestion or aerosol inhalation of Class A biosolids following regrowth in the initial biosolids was significant. Therefore, practices such as covering stored biosolids and avoiding saturated anaerobic conditions should be required for generators and distributors of biosolids.

As part of the University of Arizona evaluation of the sustainability of land application of class B biosolids, the long term effects of land application on soil microbial properties was also reviewed by Pepper et al (2008). Twenty years of annual biosolids applications to replicated field-plots demonstrated a lack of adverse effects on soil microbial numbers. In fact, land application increased microbial diversity and enhanced microbial activity. These results are in accordance with Snyder et al. (2011) who found

that biosolids borne Triclosan had no effect on soil microbial community respiration or ammonification up to the greatest concentration tested. Interestingly, reports from research on aquatic systems have shown a correlation between Triclosan concentrations in stream sediments and the number of benthic bacteria resistant to Triclosan (Drury et al. 2013). Analysis also indicated that Triclosan in sediment resulted in decreased benthic bacterial diversity and shifts in community composition. Such a comparison lends support to the argument that terrestrial systems have orders of magnitude greater microbial capability and residence times to achieve decomposition and assimilation of potential contaminants in biosolids (Overcash et al. 2005).

The University of Arizona's historic data set revealed no evidence of long term persistence of enteric pathogens in the soil. After 20 years of biosolids application, no known pathogens were detected in soils sampled nine months after the last biosolids application (Pepper et al. 2008). Furthermore, the review of the national data set showed that emerging pathogens such as *Campylobacter* and *E. coli 0157:H7* were never detected in mesophilic anaerobic digested biosolids, and *Shigella* was only detected occasionally (Pepper et al. 2010). This is not to say that risks to human health are zero, and the same authors report that adenoviruses may be more commonly present in Class B biosolids than enteroviruses, but overall, researchers from University of Arizona concluded that the risks to human health posed by pathogens within biosolids are low if current USEPA regulatory guidelines are followed.

A more recent collaboration between University of Arizona researchers and the USDA (Brooks et al. 2012) resulted in the first study comparing biosolids to manure microbial risks. Researchers used quantitative microbial risk assessment to estimate pathogen risks from occupational and public exposures during scenarios involving soil, crop and aerosol exposures. *Campylobacter jejuni* and enteric viruses provided the greatest single risks for most scenarios and the highest risks were associated with both manures and biosolids immediately at application. Comparison by pathogen group confirmed greater bacterial risks from manure whereas viral risks were exclusive to biosolids. A direct comparison of shared pathogens resulted in greater risks for manure. All pathogen risks decreased with treatment, attenuation, dilution and time between land application and exposure and nearly all risks were insignificant when using a four-month harvest delay for crop consumption.

Similarly, Viau et al (2013) performed a risk assessment of pathogen exposure, concluding that other than accidental ingestion, the highest public risks of infection from land application are associated with aerosol exposure. The authors admit that there is large uncertainty in aerosol risk values, due to limitations in current exposure models, pathogen content, and dose-response information. Ultimately, the authors concluded that a rigorous biosolids pathogen treatment process, rather than extending community separation distances, is the most efficient method for reducing pathogen exposure and infection risk.

Reported Adverse Impacts on Human and Animal Health

Over the past twenty to twenty-five years, nationwide, there have been several hundred reports of alleged adverse impacts on human health and quality of life which have been purported to have resulted from exposure to Class B biosolids. The Program is not aware of any such incidents related to the use of properly stabilized EQ biosolids, although there have been three incidents of extremely noxious odors resulting from the use of poorly stabilized EQ compost and heat dried biosolids in Vermont.

The Program is aware of only one incident reported in Vermont in which adverse health impacts to humans were alleged to possibly have been caused by exposure to Class B biosolids. That single incident

involved attendees at the multiday concert festival by the band Phish that was held on the grounds of the Newport State Airport in 2004. Agricultural fields surrounding the runways at the concert site had been used for more than a decade for the management of biosolids generated by the City of Newport's WWTF. All applications of biosolids had been conducted by subsurface injection at a depth of approximately 12 inches, with the last application having occurred some eleven and one half months prior to the concert. The permit for the concert specified that the areas to which biosolids had been applied were to be used only for parking and that camping there was not permitted. However, heavy rains during the event turned the entire festival site into a sea of mud, leading many attendees to abandon the designated camping areas and camp in or near their vehicles. Regardless, the site management practices, the use of subsurface injection (which leaves no biosolids on the soil surface), the fact that a corn crop had been grown and harvested on the sites in the intervening period, and the duration of time since the previous application event all suggest that concert attendees were exposed to minimal, if any, biosolids. Rather, all evidence examined by the Program and the VDOH indicated that the health impacts reported by festival attendees (primarily skin rashes and gastrointestinal distress) were more likely derived from exposure to raw sewage that occurred as a result of two conditions. First, the weather conditions made it impossible for pumper trucks to access the portable toilets for maintenance, causing all toilets to overflow and contaminate the ground in the area around them. The other major exposure occurred when gate crashers toppled a perimeter security fence, knocking over an entire row of full-to-capacity portable toilets that discharged their contents onto the ground, which subsequently became distributed throughout the festival site by people walking through the spilled sewage after the units were righted and immediately put back into service at the same location without any remediation of the spilled contents.

In general, the complaints of adverse health impacts resulting from Class B biosolids management predominantly include mucous membrane and eye irritation, respiratory and gastrointestinal distress, headaches, and skin rashes – although more serious effects have been alleged. Residents also report nausea derived from noxious odors and interference with their quality of life and beneficial use of their property. Typically, these incidents are reported by persons residing within about one half mile of sites on which undigested, lime stabilized biosolids or poorly prepared anaerobically digested biosolids have recently been spray applied in liquid form without incorporation into the soil.

Odors are the most frequent cause of complaints surrounding land application. Historically, odors were dismissed as purely esthetic or quality-of-life issues. However, Schiffman et al (2004) reported evidence that exposure to odor-causing chemicals can cause illness and that some airborne contaminants can cause a variety of symptoms including eye, nose, and throat irritation, headache, nausea, diarrhea, hoarseness, sore throat, cough, chest tightness, nasal congestion, heart palpitations, shortness of breath, stress, drowsiness, and alterations in mood. Schiffman's findings correlate well with those of Harrison et al (2002), who characterized symptoms of 328 people who related their ailments to the land application of biosolids. These tend to be very similar to the symptoms anecdotally related by residents alleging health impacts from land applied biosolids as well. Eliminating one potential source of noxious odor conditions was the primary driving rationale for Vermont having prohibited on-site storage of biosolids destined for land application other than for very short term staging in preparation for a land application event.

Poor anaerobic digestion of sludge, unquestionably, will often result in nuisance odors derived from reduced sulfur compounds and mercaptans. Raising the pH of undigested sludge or septage to greater than 12.0 S.U. in order to attain the pathogen reduction requirements via lime stabilization, increases the potential to produce copious amounts of gaseous ammonia and other malodorous amines. Far too often, lime stabilized biosolids or septage are delivered and applied to sites without a sufficient post lime addition holding time and the materials are still off-gassing ammonia and other malodorous compounds. For septage, the primary reason behind the VSWMR continuing its requirement for holding septage at a

minimum pH of 12.0 S.U. for two hours, rather than adopting the 30-minute hold time established in 503.32(c)(2), was to provide additional time for the reactions that produce malodorous compounds to abate. Because there is minimal hold time to allow the gas producing reactions to subside and for the gasses to dissipate prior to the biosolids or septage being applied to the land, the immediate area around such sites can be negatively impacted. This problem can be further exacerbated if such biosolids or septage are applied on windless days or under thermal inversion atmospheric conditions that tend to trap air emissions at ground level in localized areas.

Composted and heat dried biosolids also present the potential to generate noxious odors. Compost typically requires a minimum thirty-day curing period following active composting in order to allow the biological decomposition to subside and for the compost to cool to ambient temperatures. During active composting, the potential to generate noxious odors due to the production of volatile fatty acids, amines, terpinoid compounds, mercaptans, and reduced sulfur compounds can be heightened depending on the composting technology employed and on the actual composting conditions. The odorous compounds are usually contained in the mix during the active composting cycle, which must be long enough to assure decomposition to the greatest extent feasible, and during the curing cycle that allows the odorous compounds to dissipate as the biological decomposition decreases. If the active composting or curing cycle is inadequate or not provided, even EQ biosolids will have the potential to create nuisance conditions. Odor problems from heat dried biosolids generally arise when they are surface applied without incorporation and become rehydrated by precipitation.

Three such incidents have occurred in Vermont in the past 25 years, the last in 2016, two of which involved the importation of composted EQ biosolids produced in Springfield, MA, at a facility which, at that time, was processing undigested sludge without any curing cycle. In both cases (one in Tunbridge in 1995, the other in Danville in 2001), the stockpiled "biosolids" were still undergoing active biological activity and were hot to the touch, despite having met the minimal requirements of Part 503 (which does not require a curing cycle) for composted biosolids. These materials were producing copious quantities of highly malodorous amines and volatile fatty acids and both were being managed in locations that trapped those odors in valleys, resulting in particularly nauseating odor problems and a large number of complaints to the Department. In both cases, the Department ordered the immediate removal of the offending material and reached a voluntary agreement (albeit under the threat of an enforcement action if it were to recur) with the managers of the compost (different ones in each case) that they would never again import that material into Vermont. Most recently, in the spring of 2016, heat dried (not composted) EQ biosolids from Quincy, MA, were surface applied without incorporation to fields in Weathersfield. Those biosolids became rehydrated by precipitation which caused odors to generate which resulted in numerous odor complaints. The Program successfully worked with the vendor of the material to mitigate the odors. The Program, through its facility permits, has virtually eliminated odor issues with composted EQ biosolids produced by Vermont facilities by tightening the conditions of active composting and by requiring a minimum thirty-day curing cycle and temperature reduction to ambient temperatures before it may be released from the facility. However, note that the lack of regulatory oversight for EQ biosolids produced at out of state facilities and imported into Vermont (see the discussion on page 19) leaves DEC with little but local nuisance ordinances and state nuisance air pollution regulations as enforcement mechanisms to address these types of odor problems.

Gastrointestinal complaints are more difficult to relate to a specific causative agent as they may result from exposure to biosolids derived airborne pathogens and noxious odors, as well as from naturally occurring exposure to pathogens in the environment that are not associated with the management of biosolids. Although research at the University of Arizona (Rusin et al 2003, Pepper et al. 2008, Brooks et al. 2005; 2012) has found little risk from potential pathogenic content in aerosols collected downwind of

biosolids application events, the potential for exposure of residents in the immediate area cannot be entirely discounted. A review of available literature indicates that gastrointestinal complaints tend to generally be clustered around sites where liquid biosolids were spray applied under windy conditions that had a strong potential to transport aerosols off site. However, most of the causative biological agents are also relatively ubiquitous in the environment, making a definitive determination of the source tenuous at best. If an application event was also associated with exposure to noxious odors, there appears to be a relatively strong correlation with the number of gastrointestinal ailment reports, again making it more difficult to determine if the ailment is pathological in nature or derived from the adverse effects that noxious odors can have on certain members of the general population.

There have also been allegations that exposure to biosolids has been correlated to ALS (Lou Gehrig's disease), AIDS, cancer, Creutzfeldt-Jakob disease, mad cow disease, and several other uncommon serious diseases. All these purported linkages have been investigated by a number of health organizations (the Centers for Disease Control (CDC) and Mayo Clinic, among others) who have found no demonstrable evidence of any correlation.

At least four human deaths since 1990 have been the subject of allegations purportedly linking them to exposure to pathogens from the land application of Class B biosolids. In 1991, Shayne Connor of Greenfield, NH, died from what was diagnosed as unspecified 'community pneumonia' less than 24 hours after being hospitalized. Mr. Conner slept in a room at his parents' home where he kept the window open at night, and which was near fields where Class B biosolids had recently been heavily surface applied without incorporation. Numerous other residents of the neighborhood also complained of respiratory ailments following the application. Although an autopsy was unable to determine the cause of death, and the coroner who performed the autopsy said there was no evidence to suggest sludge toxins contributed to the man's death, the family settled out of court with the company managing the site for an undisclosed settlement and no admission of culpability. In 1994, Tony Behun of Osceola Hills, PA, rode his dirt bike in a field to which Class B biosolids had recently been surface applied without incorporation. Mr. Behun became ill a few days later with flu-like symptoms that persisted for a week before he was admitted to a local hospital and eventually airlifted to Pittsburgh's Allegheny General Hospital where he died of what was diagnosed as a staphylococcus (*S. aureus*) infection. The Pennsylvania Department of Environmental Protection (DEP) found no medical or scientific evidence that Mr. Behun's death was linked to contact with biosolids and the CDC was not asked to investigate the biosolids/disease correlation until 1999, by which time it was impossible to determine if such a correlation existed. In 1995, Daniel Pennock of Berks County, PA, died after contracting both rotavirus and *Staphylococcus* infections allegedly from exposure to land applied Class B biosolids on a local farm. Official interim and final reports by the Pennsylvania DEP pointed to violations by the land-applier for this site, including improper storage and stabilization of biosolids, as well as surface application without incorporation. However, these reports, as well as the subsequent investigation by the EPA, concluded that a source of the viral staph pneumonia could not be determined and that available evidence did not establish that Mr. Pennock actually had any contact with either biosolids or the land on which biosolids had been applied. In 2003, Michael Seth Jones of Erwin, TN, a farm hand who had participated in the application of Class B biosolids to his employer's fields, died of multiple causes. During autopsy, a biopsy of lung tissue matched bacterial DNA with species present in biosolids (the specific species were not cited in the available report of the incident).

With the exception of the case of Mr. Jones, these claims were cited as evidence in a 2003 Center for Food Safety et al. petition to EPA entitled "Petition Seeking an Emergency Moratorium on the Land Application of Sewage Sludge". In its response to the petition, the EPA strongly denied the claims of

adverse health effects, citing anecdotal evidence and stating that no causal connection whatsoever was established between the deaths of Shayne Conner, Tony Behun or Daniel Pennock and exposure to land-applied sewage sludge (US EPA, 2003b). Ultimately the EPA concluded that the facts presented in the petition did not support the petition for a moratorium on land application of sewage sludge.

The land application of biosolids has also alleged to have been contributory to several instances of severe adverse impacts on farm livestock. The most notorious case involved two dairy farmers, Andrew McElmurray and William Boyce, in the Augusta, GA, area who alleged that biosolids produced by the Messerly Wastewater Treatment Plant in Augusta were responsible for the death of nearly 500 head. Evidence introduced in court indicated that concentrations of cadmium, arsenic, and PCB in the "biosolids" far exceeded all regulatory standards, and that the concentration of thallium, a pollutant that is highly toxic to cattle but not regulated under federal, Georgia, or Vermont biosolids standards, was dangerously elevated. The court also found that the City's wastewater and sludge management programs were in a shambles, that records were incomplete and likely falsified, that sludge was applied to the sites far in excess of agronomic and cumulative pollutant loading rates, and that the City failed to maintain the sites' soil pH in the proper range (United States District Court, S.D. Georgia, Augusta Division, 2008). This was a situation highlighting what can go wrong when the regulatory frameworks and standards and required management practices are not observed and gross mismanagement occurs.

Two other notable cases of alleged adverse health impacts on herds and the resident farmers involved the farms of Jim Bynum, outside of Kansas City, MO; and the Zander farm in Lynden, WA. Both Mr. Bynum and the Zanders have related a large number of herd problems and multiple ailments suffered by members of their families to sludge management at sites on or adjacent to their dairy farms. Again, the evidence in both cases points to these incidents as cases of what can go wrong if biosolids are not appropriately managed. In both of these cases, the adverse effects have been related to groundwater contamination derived from excessive application rates and failure to control soil pH as well as allegations of exposure to other toxic compounds volatilized from the biosolids applied to the sites.

The only case that has been reported to any State agency in Vermont alleging adverse impacts to livestock due to exposure to biosolids involved biosolids produced by the City of Rutland's WWTF and Robert Ruane - a local farmer. Between November 1987 and December 1990, the City applied biosolids to three fields on the Ruane Farm in Clarendon, Vermont. A total of approximately 210 wet tons of sludge (estimated from the 42 dry tons reported, at 20% solids) was applied to three fields totaling 87 acres at the loading rates and resulting masses of cadmium and lead applied as reported in Table 10.

Table 10. Ruane Farm: Loading rates (dry tons/acre).

Site	Acreage	dry tons/ac applied	lbs/ac Cd applied	lbs/ac Cd limit	lbs/ac Pb applied	lbs/ac Pb limit
8	37	19.20	0.36	4.5	11.16	268
8A	20	4.40	0.11	4.5	4.39	268
9	30	18.10	0.32	4.5	14.10	268

Table 11. Ruane Farm: Annual application rates (dry tons/acre).

Land Application Date	Field 8	Field 8A	Field 9
November 1987	1.25		
May 1988	2.57		4.47
October 1988	0.67		
November 1988	1.26		
March 1989	1.30		
April 1989		4.39	
May 1989			2.52
November 1989	2.30		
March 1990	**1.30**		
April- 1990	**8.57**		
November 1990			**5.55**
December 1990			**5.55**

The annual application rates to each site appear to be lower than the annual nitrogen based agronomic rate for a corn crop (typically about 5 to 6 dry tons biosolids/acre), with the exception of the combined March and April 1990 applications to Site #8 and the combined November and December 1990 applications to Site #9 (bold highlight in Table 11); which, under most scenarios, would *suggest* that the agronomic rate was exceeded.

However, it was not possible to calculate an accurate application rate to verify or refute that notion for any of these events, as it is not known if additional nutrients were being applied to the sites from manure and/or chemical fertilizers in those and the preceding three years (or at what rate, if they were), and the nitrogen content of the biosolids and nitrogen requirement of the corn strain that was sown is unknown.

During this period the cadmium concentration in the sludge averaged 9.03 mg/kg, dry weight, within a range of 5.6 – 18.7 mg/kg, dry wt.; and the lead concentration in the sludge averaged 382.5 mg/kg, dry wt., within a range of 49.8 – 791.0 mg/kg, dry wt. All cadmium concentrations met all former and current regulatory standards. The lead concentrations never exceeded the federal or Vermont regulatory standards in effect at the time (1000 mg/kg, dry wt.) or the current 503.13 – Table 1 ceiling concentration of 840 mg/kg, dry wt., but the majority did exceed the current standard (Vermont and 503.13 – Table 3) of 300 mg/kg, dry wt. The Vermont APLR for cadmium (0.45 lbs Cd/acre-year) was never exceeded in any 365-day period during the sites use, nor was the federal APLR for lead (18.67 lbs Pb/acre-year) ever exceeded; and indeed, the total cumulative mass of each pollutant applied to the sites over the three years of their use do not even exceed the annual pollutant loading limits.

In 1988, Mr. Ruane began to notice health changes in his dairy herd. In a proceeding before the Waste Facility Panel (appeal of City of Rutland Interim Certification #I9125, 1992), Mr. Ruane testified that his cows acted arthritic, lost weight, aborted calves and wouldn't breed back, and there appeared to be a high mortality rate. In addition, Mr. Ruane testified that the corn crop planted in the spring of 1989 on Site #9 failed after having had 2.52 dry tons/acre of biosolids applied. However, the same seed planted on the other two sites that year produced successful corn crops, despite Site #8 having received an application of biosolids of 1.3 dry tons/acre and Site #8A having received nearly twice the Site #9 loading at 4.39 dry tons/acre. Subsequently, over the next year, relations between the City and Mr. Ruane deteriorated over these and numerous other issues, and the use of the Ruane Farm for biosolids management ceased, with

the last applications occurring in December 1990. Subsequently, all sludge produced by the City's WWTF has been disposed in landfills.

Investigations of Mr. Ruane's claims were conducted by the Program and the (then) Department of Agriculture, Food, and Markets (DAFM), but only very limited documentation of findings could be located in the Program's files, as the majority were lost during the Tropical Storm Irene flooding of the Program's offices in Waterbury. The remaining information regarding the Program's investigation includes limited soil (Table 12) and groundwater (Table 13) data from that period. All soil data apparently date from post-December 1990, which indicate a *potential* concern regarding the cadmium and lead concentrations in soil, which are slightly higher than the range typical for the soil types present on the sites (the *potential concern* is primarily because no background native soil data for the site could be found for comparison with the biosolids amended soil concentrations).

However, the few groundwater data available document that the cadmium and lead concentration greatly exceeded current groundwater protection standards. Those standards were higher in 1989 than today, and although a copy of the standards in effect at the time could not be located, the lead and cadmium concentrations bold highlighted in Table 13 still exceed any groundwater standards known to have been in effect in any jurisdiction at that time. Records establishing the definitive location of the monitoring wells could not be located either, although a sketched site plan depicting general monitoring well locations indicates that there were two monitoring wells associated with the sites, both on Site #9. Well 9 East was the upgradient well and Well 9 West was the down gradient well. Again, no pre-application background groundwater data could be located, the sketch map does not show any wells located on either Site 8 or Site 8A, and no groundwater monitoring data for those sites is in the Program's files. It should also be noted that this area of Clarendon has historically been the focus of investigations and enforcement actions taken by the DEC against several industrial facilities over incidents of illegal waste management and disposal. Residents of North Clarendon, well removed from the vicinity of the Ruane farm, have also engaged VDOH to investigate what they perceive to be an unusual cluster of relatively rare cancers in the general area. VDOH found that there was not a statistically significant increase in the local cancer rate.

However, relative to these local health concerns as they relate to the Ruane situation; the General Electric plant located on Windcrest Rd., about ½ mile directly uphill of Site 9 on the Ruane Farm, operated an unlined landfill at the plant's location from 1979 to 1986 in which lead and other metal hydroxide sludges generated by the G.E. facility was disposed, and G.E. was fined $30,000 in 1989 for illegally disposing of lead contaminated wastes at the facility. The impact of those activities on groundwater flowing beneath the Ruane Farm and the potential that they are the source of the lead contamination is unknown, although the presence of significantly elevated lead concentrations in the upgradient monitoring well lends substantial credence to the position that biosolids managed on the farm were not the source. It must also be noted that the lead and cadmium concentrations in the groundwater samples taken from the wells on Site #9 were already several orders of magnitude above standards prior to any biosolids being applied to that site, where the April 1988 lead concentrations were all approximately 17 mg/L and the cadmium concentrations were also elevated, yet biosolids were not present on Site #9 until May of that year (although some biosolids had been both stored in a PVC lined concrete bunker and relatively lightly applied on Site #8, nearly ¼ mile from the Site #9 monitoring wells, in November 1987) – a fact that essentially precludes biosolids as being the source of the groundwater contamination. An analysis of the corn crop grown on each of the sites during the summer of 1989 yielded results that were below analytical detection limits for both cadmium and lead (the detection limits were not reported). Thallium and other unusual metals of similar toxicity to cattle were not being used by any area industries at the time; so although not subjected to an analysis for those pollutants, their presence in any significant concentration in the sludge would not be expected.

Table 12. Ruane Farm: post-application cadmium (Cd) and lead (Pb) soil concentrations (mg/kg, dry wt.).

Site	Soil Cd	Typical Natural Soil Cd Range	Soil Pb	Typical Natural Soil Pb Range
8	0.78	0.55 – 0.85	22.3	8.1 – 19.9
8A	0.75		21.0	
9	0.88		21.1	

Table 13. Ruane Farm: Concentrations (mg/L) of lead (Pb) and cadmium (Cd) in groundwater.

Monitor Well	Test Date	Pb	Cd	Notes
9	4/26/1988	**17.1**	**0.43**	Site #9. Specific well not identified
9	4/26/1988	**16.5**	**1.28**	Site #9. Specific well not identified
9	6/3/1988	< 5.0	< 1.0	Site #9. Specific well not identified
9E	5/2/1988	**17.0**	< 1.0	
9E	5/2/1988	**17.0**	< 1.0	duplicate of previous test
9E	4/28/1989	< 1.0	< 1.0	
9E	4/23/1990	**29.0**	< 0.2	
9W	5/2/1988	**8.0**	< 1.0	
9W	4/28/1989	< 1.0	< 1.0	
9W	4/23/1990	< 5.0	**0.9**	
Preventive Action Limits		.0015	.0025	VT Groundwater Protection Standards
Enforcement Standards		.015	.005	

The DAFM investigation related to Mr. Ruane's concerns regarding his herd's health was conducted by two of that Department's employees. Their report to the Commissioner of DAFM, while non-conclusive as to an assignment of cause, did specifically note several issues and deficiencies in Mr. Ruane's operations, including:

- Anecdotal evidence that his farm management was marginal;
- Anecdotal evidence that the cause of the crop failure on Site #9 in 1988 was the result of sowing seed on soil that was too wet;
- Cows were aborting calves and not breeding back;
- The "sick" animal at the farm at the time of the investigation had a number of calving problems, including an infected uterus;
- The herd had a history of foot problems, including elongated toes;
- Silage quality was marginal;
- The recommended feeding program for lactating dairy animals was not being observed;

- The one forage sample analyzed had an elevated copper content, although it was lower than what the NRC considers to be toxic to dairy cattle;
- A cull rate of 50 animals over three years was not unusual (given the size of the herd), as a cull rate of 25% - 30% is the average range; and,
- That Mr. Ruane was a livestock transporter and operated an open herd, whereby numerous head were shuttled on and off the farm.

The report did state however, that not enough testing of forage had been conducted and that the link between the herd's water supply, groundwater contamination, and sludge management should be investigated further. The Program is unable to locate any documentation that these additional investigations were conducted. Other testimony presented to the Waste Facility Panel by Mr. Ruane (also re: appeal of City of Rutland Interim Certification #I9125, 1992) indicated that an autopsy of one deceased cow and blood tests on several other sick cows was apparently conducted at Cornell University at Mr. Ruane's initiative; but again, no reports of the results could be located. It must also be noted that Mr. Ruane claimed a misunderstanding in the information provided to the DAFM investigation team, in that he also testified in the same Waste Facility Panel proceeding that the feeding program he had related was what he provided in each feeding (done three times each day) and were not the daily aggregate totals as the report to the Commissioner suggested. The Program has not been able to confirm or refute Mr. Ruane's testimony.

Ultimately, neither the Program's or the DAFM investigations were able to establish any definitive link between the use of Mr. Ruane's fields for biosolids management and the adverse health conditions experienced by his herd.

Septage

Any regulatory reform for residual waste management must consider the issues surrounding septage management in Vermont. In 2015, more than 51,800,000 gallons of septage was managed in Vermont, of which approximately 99% was pumped from the tanks of Vermont residences. Of that total volume, approximately 6.1 million gallons was managed via direct application to approximately 220 acres of agricultural lands, following stabilization with hydrated lime to achieve the Class B pathogen reduction standard (See Appendix 4: Table A-6).

The average concentration of contaminants in Vermont generated septage, as determined from a continually updated database (as of September 2016, calculated using the full detection limit for results that are "less than") is provided in Table 14, as are data taken from a larger regional set of analytical results. For the purpose of calculating the remaining useful life of septage land application facilities, the Program takes a conservative approach and uses the highest value from the two data sets.

Table 14. Average metals concentrations (mg/kg, dry wt.) and solids percentage (%) in septage.

Pollutant	Concentration	
	Regional data	Vermont data
As	7.56	8.57
Cd	5.34	2.94
Cr	36.94	17.59
Cu	724.77	519.01
Hg	1.59	1.18
Mo	30.77	14.28
Ni	30.64	18.76
Pb	75.93	39.26
Se	7.41	9.84
Zn	1113.12	895.74
% solids	2.39	1.97

There is relatively little difference in composition between septage that is directly applied to the land in comparison to the biosolids produced in a WWTF. Although the treatment of sewage and digestion of sludge will result in greater decomposition of many CECs due to the higher operating temperatures, septage that has accumulated over a number of years in a septic tank has also undergone a significant level of anaerobic digestion, albeit at a lower temperature. However, insofar as decomposition of the organic components are concerned, the degree of digestion achieved in a septic tank is less than that achieved in an anaerobic digester due to the significantly longer detention time but at ambient ground temperatures, and lime stabilization provides essentially the same degree of pathogen reduction as is provided by anaerobic digestion to Class B pathogen reduction standards.

As an aside, three of the operators of septage land application programs have stated their intention to retire within the next five to seven years. The discontinuance of these three land application programs will entail the termination of approximately 110 acres (50% of the currently approved acreage) permitted for this use. All three facilities are located in areas of the state where the need to utilize other options for septage disposal will entail significantly longer haul distances to facilities that accept septage.

On average, operators of septage land application programs utilize approximately 32% of their maximum permitted application capacity each year. Put into perspective, the volume actually applied if the maximum permitted application capacity were to be used represents loading each of the 220 acres with the approximate equivalent of a 1.7" rain event spread out over about a six-month period. By comparison, the septic system for a four bedroom home located on soils with midrange permeability, loads the approximate equivalent of a 3" rain event each year to the area of the leachfield – essentially the same as the hydraulic loading of land application sites during those periods of the year when they can be used. (see Table 15). Because the amount of liquid applied to a site in each application event is so low, the Program has never observed or been able to confirm a report of the direct runoff of septage from any site since enhanced regulatory oversight was implemented nearly 25 years ago. This is further supported by monitoring that was conducted as permit requirements in the late 1990s both upstream and downstream of septage and biosolids land application sites proximate to a surface water, in both dry and wet weather conditions, where analyses for bacterial contamination and nitrogen contamination showed

no discernable difference in water quality between the sampling locations and in some cases actually detected greater concentrations upstream of the sites than was found at the downstream sampling points.

Table 15. Comparison of typical permitted loading rate for various septage management options

Septage Management System	Typical Permitted Loading Rate (gal/ft^2/day)
direct land application	0.2 (see Note 1)
single residence leachfield	2.0 (see Note 2)
indirect discharge leachfield	0.5 (see Note 3)

Note 1 – based on full use of a maximum application rate of 70,000 gal/acre-year
Note 2 – single residence of four people, median permeability soils
Note 3 – system design flow >6,500 gal/day, median permeability soils

In developing the future strategy for septage management, regardless of one's position on the issue of its management via direct land application, the greater picture of septage management in Vermont, in general, must be considered. Currently, the capacity of WWTFs to accept septage varies widely in the state. As is evident from the map of facilities (Figure 1, on page 5), there are many areas of Vermont where there is very limited, or no capacity at local WWTFs to accept septage. The greatest volume capacity for septage receiving is in the Chittenden County area, the area of the state with the greatest percentage of its population residing and working in areas served by centralized sewage collection systems (apx. 65%). Both the Northeast Kingdom and the southwestern portions of the state face a severe lack of facilities for septage management. This leaves but two options for the disposal of the majority of septage generated in Vermont – land application, or a long transportation distance and cost to the nearest incineration facility or WWTF that will accept the septage. As fuel costs and WWTF operating costs increase, pumping and tipping fees rise at a commensurate rate. Septage haulers, out of necessity, must pass the associated costs of pumping, transporting, and disposing a tank's contents on to the customer. The potential downside of a radical increase in the cost of septage disposal is that homeowners will delay or refrain entirely from having septic tank maintenance done, thereby exacerbating the incidence of septic system failures. This will mainly be driven by the inability of homeowners to pay a sizable lump sum (often $300 or more) to have their septic tank pumped; as opposed to making small monthly or quarterly payments, as is the case with residences that are on municipal sewer systems.

One Vermont municipality, the Town of Londonderry, has addressed this situation by developing and permitting a land application site for the management of locally generated septage. Approximately 200,000 gallons of septage is now managed at this site annually, at a significantly lower cost than would be incurred by transporting it to the next nearest facilities that accept septage, in Bellows Falls or Springfield. As a side benefit, the Town's site, which is located on the former cover material borrow area adjacent to the old, now closed Town landfill, has been successfully reclaimed and now bears an excellent vegetated cover which has virtually eliminated the severe erosion that was occurring on the site previous to its reclamation. The availability of land application as a more cost effective disposal option, which can provide additional side benefits, must therefore be considered.

The Program has long advocated the development of a state-wide program under which owners of septic systems would be billed easily affordable amounts on a regular cycle (monthly or quarterly), and the fees

placed in an escrow account which would then be used to reimburse septage haulers for servicing systems on a regular basis at appropriate intervals.

Economics

While this paper will forego an in-depth analysis of the economics of sludge and biosolids management, under the belief that adequate protection of human health and the environment is the tantamount goal of any environmental regulations and the ultimate aim of this process, due consideration must be given to cost factors in the overall question of the sustainability of what Vermont's residents can, and are, willing to bear.

In 2015, approximately 9,850 dry tons (~67,675 wet tons at 15% solids) of sludge/biosolids and 51.8 million gallons of septage was generated and disposed in Vermont at an approximate disposal cost of $20.6 million (based on $94 per wet ton for sludge/biosolids and $275 per 1000 gallons of septage), an amount that is exclusive of the cost of preparing the sludge/biosolids portion for disposal. Preparation costs include the operation of digesters, polymers to assist solids removal, dewatering, storage, and analytical costs, among others. It is estimated that approximately 40% of a WWTFs total annual operating cost is spent on solids management. The Program expects a significant increase in sludge production over the next decade as a result of the increased solids production that will result from the need to remove greater amounts of nitrogen and phosphorus from sewage due to the Long Island Sound and Lake Champlain TMDLs.

Although DEC has not conducted its own analysis of disposal costs on a state-wide basis, similar studies conducted by CSWD, the Center for Rural Pennsylvania, and a New Hampshire legislative commission resulted in relatively comparative cost estimates which can provide insight within a regional context (Table 16).

The studies conducted in New Hampshire and Pennsylvania were intended to examine the costs of various disposal options – primarily land application, landfilling, and incineration. The CSWD data are slightly different in that they compare the cost of landfilling and the cost of disposal via shipping to the Grasslands Facility in Chateauguay, NY, for additional processing to EQ biosolids standards.

Table 16. Comparative cost ($US) of sewage sludge disposal options (per wet ton).

Management	New Hampshire	Pennsylvania	CSWD (VT)
landfill	$75	$75	$94
land application	$40	$62	$130 (class A) $100 (class B) $90 (Grasslands)
incineration	$71	$71	No Data

Although the Pennsylvania study did not examine the comparable costs for septage management, this issue was examined in detail by the New Hampshire Commission's report to the legislature, which found

a similar differential between land application and disposal at a WWTF. Based on tipping fees alone (i.e. – the per gallon cost, exclusive of transportation costs, other business costs, profit margins, etc.), the New Hampshire study found that disposal at a WWTF was approximately $78 per 1000 gallons and that disposal via land application was at a cost of approximately $25 per 1000 gallons.

Obviously, a direct comparison of disposal costs across the region cannot be made from these data. This is primarily due to regional variations in landfill and WWTF tipping fees, variations in fuel costs and haul distances, state and local taxes, etc. However, the cost of the various management options relative to each other are consistent in these cases and with anecdotal information gathered from other areas around the country. In general, it appears that land application can provide a distinct cost advantage over landfilling and incineration as management strategies. The New Hampshire and Pennsylvania studies also documented that there is a distinct economy of scale associated with land application, where its cost advantage over other disposal options varies in direct proportion to the volume of biosolids that are being managed. In Vermont, this cost differential is not expected to be as great as in other jurisdictions, primarily due to the costs added by the management practices and monitoring requirements imposed on land application under Vermont's program that are not required in most other jurisdictions. These requirements, though not completely unique to Vermont, include: more frequent analyses of biosolids; groundwater, soil, and plant tissue testing; a ban on field storage of biosolids (meaning that a storage facility located at the WWTF is necessary); requirements to incorporate biosolids into the soil following application; etc. Although these practices do reduce the cost differential between land application and other management strategies, the Program considers them essential to assuring the integrity and scope of its oversight. As such, the Program does not recommend any relaxation of the monitoring required of land application programs, other than eliminating the requirement to perform the Toxicity Characteristic Leaching Procedure (TCLP) analysis which is wholly unsuited to an analysis of the biosolids matrix.
An additional cost of solids management in Vermont comes through the imposition of the Franchise Tax on Waste Facilities. This tax, of $6 per ton of solid waste disposed, is authorized at 32 V.S.A. 5952, with certain exemptions being provided in 32 V.S.A. 5953. The exemptions provide that sludge wastes delivered to a recycling or composting facility or septage or sludge delivered to a facility other than a landfill or incinerator are not subject to the franchise tax. As such, biosolids that are managed via land application or treatment to the EQ biosolids standards are exempt from the tax. A prohibition on the land application of biosolids and corresponding switch to solely landfill disposal would result in the need to landfill approximately 65,700 wet tons (approximately 106,500 $yd^{3)}$ of sludge annually, thereby consuming approximately 3% of Waste USA's remaining capacity each year, and would increase disposal costs by about an additional $350,000 per year (based on 2014 disposal rates) in solids management costs across the state, as the Solid Waste Franchise Tax is assessed on the wet tonnage of biosolids disposed.

In early 2015, the CSWD conducted a detailed analysis of various means of managing biosolids produced by the WWTFs in its member's towns. CSWD is the sole solid waste management district in Vermont that has assumed overall responsibility of biosolids management. CSWD conducted a broad examination of the pros and cons of various technologies, including the economics of each, in its evaluation of how to best manage this waste stream in the future. CSWD's April 2015 report (which is not available on-line) of the study's findings provided the following data:

Table 17. Sludge management options, benefit, and cost per wet ton in Vermont

Management Option	Benefit	Cost per wet ton
liquid sludge → dewatering → landfill	• none	$93.87 -$98.02
liquid sludge → dewatering → Casella Grasslands facility	• land applied as EQ	$89.88
liquid sludge → dewatering → thermal drying	• land applied as EQ	$200 -$285
liquid Sludge → dewatering → thermal drying → gasification	• produces methane usable as fuel	$300 -$350
liquid sludge → dewatering → composting	• land applied as EQ	$110 -$175
liquid sludge → dewatering → alkaline stabilization	• land applied as EQ	$100
liquid sludge → mesophilic anaerobic digestion → dewatering	• land applied as Class B • produces methane usable as fuel	$130 -$150
liquid sludge → thermophilic anaerobic digestion → dewatering	• land applied as EQ • produces methane usable as fuel	$140 -$160
liquid sludge → mesophilic anaerobic digestion → thermophilic anaerobic digestion → dewatering	• land applied as EQ • produces methane usable as fuel	$110 -$130

Management Alternatives

In Vermont, infrastructure for residual waste management is currently provided only by municipalities and private sector generators, there is no federal or state owned or operated infrastructure. Limited state funding is available to municipalities that construct new biosolids management infrastructure as part of a WWTF upgrade, but no such public funding is available to the private sector generators or residual waste managers. The Program does not promote the implementation of any specific technologies or management strategies beyond what is mandated in order to achieve compliance with the requirements of the CWA. In general, while the Program will assist municipalities and private entities in the evaluation of upgrades or new infrastructure involving currently standard or emerging technologies for their ability to meet the proponent's claims, environmental and health safety concerns, and compliance with and ability to meet all regulatory standards; the Program refrains from promoting or mandating one technology over another.

In summary, there are only three broad basic means by which biosolids can be managed or disposed: land application, landfilling, or incineration – although there are a variety of specific technologies within each of those categories. The use of some emerging technologies such as pyrolization (gasification), thermal drying, ozonation, etc., all result in the production of their own waste streams or final products that must still be managed via one of the three basic options. There are no incineration facilities in Vermont and it is unlikely that one could be sited here given their sordid history in the state. The CSWD built a heat dryer and pelletizing facility in South Burlington in the mid-1990s. The operation of that facility was very short lived due to significant odor problems, mechanical problems (mainly based on a lack of redundant material handling systems), and difficulties in producing a marketable pelletized EQ biosolids product.

There are a few emerging technologies, such as minergy, glassification, or conversion to synfuels, that also result in marketable end products. Minergy and glassification produce a dry material that can be incorporated into construction materials, and conversion to synfuels produces a marketable alternative fuel. However, these technologies are all substantially more energy intensive, come with higher capital costs for the facilities, and entail higher annual operation and maintenance costs than any of the three basic management options. Cost estimates for those technologies are generally in the range of $250 per wet ton and higher. Those technologies are also highly cost dependent on the economy of scale, with larger facilities being significantly more economical on a cost per ton treated basis, so any practical use of them in Vermont in order to be economically feasible, would likely necessitate regional facilities and the associated costs of transporting sludge from local WWTFs to the regional facilities. EPA has produced a report, "Emerging Technologies for Biosolids Management", which provides an excellent overview of most currently available and emerging technologies, and reaches most of the same conclusions as CSWD's analysis.

That EPA report evaluated approximately 90 different emerging technologies for the treatment of sludge prior to its ultimate use or disposal. Those technologies were grouped into the broad headings of conditioning, thickening, stabilization, dewatering, thermal conversion, drying, and other processes. It must be noted that in all of the technologies evaluated, none result in the complete destruction of sludge and all produce their own type of residual waste that must still be managed via one of the three basic options (land application, landfilling, or incineration), although several do produce an end product (typically an ash) that is potentially suitable for incorporation into other products (asphalt, concrete, building materials, glass, etc.) rather than landfilling. Even the process of converting sludge to synfuels leaves its own type of sludge which must be appropriately managed. These ash or tar-like end byproducts are not suitable for application to the land (the metals have been concentrated, the protectiveness derived from the original organic content of the sludge destroyed, and there is no longer any nutrient or soil conditioning value), nor are they amenable to incineration (they have already been "incinerated"), so the sole remaining disposal option is use in other products or landfilling.

It must also be recognized that none of the technologies resulting in an end product with the potential to be managed via application to the land provide any significant reductions in the potential suite of contaminants that may be contained in the biosolids, and therefore do little to mitigate the concerns their presence may present related to protection of groundwater and water quality in land application management strategies. While ozonation or filtration through activated carbon media of finished WWTF effluent likely provides the most efficient means of removing unwanted organic compounds prior to discharging the effluent to surface waters, these technologies are generally very limited in their efficiency and come with excessively high operating and maintenance costs when used in an attempt to remove those same pollutants from influent sewage before they are partitioned into the sludge during the biological treatment processes. These limitations mainly derive from all the other "trash" and organic matter that is typically found in sewage influent and its impact on filter media longevity (which itself is very expensive to maintain and replace) or the need to produce ozone in sufficient quantities to reach the target pollutants as well as the ozone reactive trash and other organic material in the influent (an exceedingly expensive proposition in its own right, as ozone requires large amounts of electrical power to generate). For those same reasons, ozonation and activated carbon filtration are highly inefficient, if not unworkable, processes for the removal or destruction of unwanted pollutants in sludge, biosolids, and septage.

Regardless of the limited set of alternative management options currently available for septage and solids management, any consideration of a mandate to manage these materials in a manner other than by application to the land (as either Class B or EQ biosolids) must consider the implications of such an

action. 47,857 wet tons of sludge was processed to biosolids standards and ultimately applied to the land in 2015. Although 67% of that total was processed at out-of-state facilities, and the majority likely applied in areas proximate to the facility at which it was treated (absent data, the amount imported back into Vermont is unknown), approximately 16,000 wet tons of biosolids was processed in Vermont and applied to Vermont lands. In addition, approximately 10.3 million gallons of septage was managed by application to Vermont lands and approximately 3.2 million gallons of septage and 700 wet tons of sludge was disposed at incineration facilities in 2015. Because most incinerators proximate to Vermont are closing in early 2016 rather than upgrading to new federal air pollution control standards, there already exists a significant volume that will soon need to be disposed elsewhere.

References

American Society for Microbiology. 2011. "Land Application of Organic Residuals: Public Health Threat or Environmental Benefit?" http://www.asm.org/index.php/component/content/article?id=7489:biorep8-2011

Andrews, WJ, JR Masoner, and IM Cozzarelli. 2012. "Emerging Contaminants at a Closed and an Operating Landfill in Oklahoma." *Ground Water Monitoring & Remediation* 32(1): 120-130.

Bassil, RJ, II Bashour, FT Sloiman and YA Abou-Jawdoh. 2013. "Antibiotic uptake by plants from manure-amended soils." *Journal of Environmental Science and Health, Part B: Pesticides, Food Contaminants and Agricultural Wastes* 48(7): 570-574. http://dx.doi.org/10.1080/03601234.2013.774898

Beecher, N. 2008. "A Greenhouse Gas Emissions Analysis of Biosolids Management Options for Merrimack, NH." Northeast Biosolids and Residuals Association (NEBRA). April 2008. http://www.nebiosolids.org/uploads/pdf/MerrmckC02AnalysFINALApr08.pdf

Beecher, N. 2012. "Current Biosolids Use, Regulatory Trends, and Public Perception in New England." *Journal of the New England Water Environment Association* 46(3) (Fall 2012): 17-25.

Blair, BD, JP Crago, CJ Hedman and RD Klaper. 2013. "Pharmaceuticals and personal care products found in the Great Lakes above concentrations of environmental concern." *Chemosphere*, 1–8.

Boxall, ABA, and P Johnson. 2006. "Uptake of Veterinary Medicines from Soils into Plants." *Journal of Agricultural* (3): 2288–2297. http://pubs.acs.org/doi/abs/10.1021/jf053041t

Brooks, JP, SL Maxwell, C Resnging, CP Gerba and IL Pepper. 2007. "Occurrence of antibiotic-resistent bacteria and endotoxin associated with the land application of biosolids." *Canadian Journal of Microbiology* 53: 616-622.

Brooks, JP, MR McLaughlin, CP Gerba and IL Pepper. 2012. "Land Application of Manure and Class B Biosolids: An Occupational and Public Quantitative Microbial Risk Assessment." *Journal of Environmental Quality* 41(6): 2009-2023.

Brown, SL, RL Chaney, J Hallfrish, JA Ryan and WR Beti. 2004. "In situ soil treatments to reduce the phyto- and bioavailability of lead, zinc, and cadmium." *Journal of Environmental Quality* 33: 522–531.

Brown, S, M Sprenger, A Maxemchuk and H Compton. 2005. "Ecosystem Function in Alluvial Tailings after Biosolids and Lime Addition." *Journal of Environmental Quality* 34: 139-148.

Chambers BJ, FA Nicholson, M Aitken, E Cartmell, and C Rowlands. 2003. "Benefits of Biosolids to Soil Quality and Fertility. *Water and Environment Journal* 17(3): 162-167

Calderón-Preciado, D, V Matamoros, and JM Bayona. 2011. "Occurrence and Potential Crop Uptake of Emerging Contaminants and Related Compounds in an Agricultural Irrigation Network." *The Science of the Total Environment* 412-413 (December 15): 14–9. http://www.ncbi.nlm.nih.gov/pubmed/22030249

Canadian Council of Ministers of the Environment. 2009. The Biosolids Emissions of Assessment Model (BEAM): A Method for Determining Greenhouse Gas Emissions from Canadian Biosolids Management Practices. PN 1432. http://www.ccme.ca/assets/pdf/beam_final_report_1432.pdf

Chambers BJ, FA Nicholson, M Aitken, E Cartmell, and C Rowlands. 2003. "Benefits of Biosolids to Soil Quality and Fertility. *Water and Environment Journal* 17(3): 162-167.

Chaney, RL, J Ryan, G O'Connor. 1996. "Organic contaminants in municipal biosolids: Risk assessment, quantitative pathways analysis, and current research priorities." *Science of the Total Environment* 185: 187-216. http://www.researchgate.net/publication/223925289_Organic_contaminants_in_municipal_biosolids_risk_assessment_quantitative_pathways_analysis_and_current_research_priorities

Chaney, RL, JA Ryan, and SL Brown. 1999. "Environmentally acceptable endpoints for soil metals". pp. 111- 155. *In* W.C. Anderson, R.C. Loehr and D. Reible (eds.) Environmental Availability of Chlorinated Organics, Explosives, and Metals in Soils. *American Academy of Environmental Engineering*, Annapolis, MD.

Clark, BO and SR Smith. 2011. Review of 'emerging' organic contaminants in biosolids and assessment of international research priorities for the agricultural use of biosolids. *Environment Internationl* 37: 226-247. http://www.bibra-information.co.uk/site_files/Clarke%20%26%20Smith%202010.pdf

Cortés, JM, E Larsson, and JA Jönsson. 2013. "Study of the Uptake of Non-Steroid Anti-Inflammatory Drugs in Wheat and Soybean after Application of Sewage Sludge as a Fertilizer." *The Science of the Total Environment* 449 (April 1): 385–9. http://www.ncbi.nlm.nih.gov/pubmed/23454699

Dodgen, LK, J Li, D Parker, and JJ Gan. 2013. "Uptake and Accumulation of Four PPCP/EDCs in Two Leafy Vegetables." *Environmental Pollution (Barking, Essex : 1987)* 182C (July 30): 150–156. http://www.ncbi.nlm.nih.gov/pubmed/23911624

Dolliver, H, K Kumar, and S Gupta. 2007. "Sulfamethazine Uptake by Plants from Manure-Amended Soil." *Journal of Environment Quality* 36 (4): 1224–1230. https://www.agronomy.org/publications/jeq/abstracts/36/4/1224

Drury, B, J Scott, EJ Rosi-Marshall, JJ Kelly. 2013. "Triclosan Exposure Increases Triclosan Resistance and Influences Taxonomic Composition of Benthic Bacterial Communities." *Environmental Science & Technology* 47: 8923-8930. http://www.ncbi.nlm.nih.gov/pubmed/23865377

Edwards, M, E Topp, CD Metcalfe, H Li, N Gottschall, P Bolton, W Curnoe, M Payne, A Beck, S Kleywegt, DR Lapen. 2009. "Pharmaceutical and personal care products in tile drainage following surface spreading and injection of dewatered municipal biosolids to an agricultural field" *Science of the Total Environment* 407: 4220-4230.

Eggen, T, TNAsp, K Grave, and V Hormazabal. 2011. "Uptake and Translocation of Metformin, Ciprofloxacin and Narasin in Forage- and Crop Plants." *Chemosphere* 85 (1): 26–33. http://www.ncbi.nlm.nih.gov/pubmed/21757221

Eggen, T, ES Heimstad, AO Stuanes, and HR Norli. 2013. "Uptake and Translocation of Organophosphates and Other Emerging Contaminants in Food and Forage Crops." *Environmental Science and Pollution Research International* 20 (7) (July): 4520–31. http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=3695667&tool=pmcentrez&rendertype=abstract

Fries, GF. 1996. "Ingestion of Sludge Applied Organic Chemicals by Animals." *The Science of the Total Environment* 185 (1-3) (June 21): 93–108. http://www.ncbi.nlm.nih.gov/pubmed/8643962

Gottschall, N, E Topp, C Metcalfe, M Edwards, M Payne, S Kleywegt, P Russell, and DR Lapen. 2012. "Pharmaceutical and Personal Care Products in Groundwater, Subsurface Drainage, Soil, and Wheat Grain, Following a High Single Application of Municipal Biosolids to a Field." *Chemosphere* 87 (2): 194–203. http://www.sciencedirect.com/science/article/pii/S0045653511013877

Hale, RC, MJ La Guardia, E Harvey, D Chen, TM Mainor, DR Luellen, and LS Hundal. 2012. "Polybrominated Diphenyl Ethers in U.S. Sewage Sludges and Biosolids: Temporal and Geographical Trends and Uptake by Corn Following Land Application." *Environmental Science & Technology* 46 (4) (February 21): 2055–63. http://www.ncbi.nlm.nih.gov/pubmed/22295899

Harrison, EZ, SR Oakes, MHysell, and A Hay. 2006. "Organic Chemicals in Sewage Sludges." *The Science of the Total Environment* 367 (2-3) (August 31): 481–97. http://www.ncbi.nlm.nih.gov/pubmed/16750559

Harrison, EZ, SR Oakes. 2002 "Investigation of Alleged Health Incidents Associated With Land Application of Sewage Sludges." *New Solutions* Vol. 12(4) 387-408. http://cwmi.css.cornell.edu/Sludge/Newsolutions.pdf

Hartman WJ Jr. 1975. "An evaluation of land treatment of municipal wastewater and physical siting of facility installations". U.S. Department of the Army, Washington, DC

Heidler, J & RU Halden. 2007. "Mass balance assessment of triclosan removal during conventional sewage treatment." *Chemosphere, 66*(2), 362–369. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/16766013

Herklotz, PA, P Gurung, B Vanden Heuvel, and CA Kinney. 2010. "Uptake of Human Pharmaceuticals by Plants Grown Under Hydroponic Conditions." *Chemosphere* 78 (11): 1416–1421. http://www.ncbi.nlm.nih.gov/pubmed/20096438

Holling, CS, JL Bailey, BVanden Heuvel, and CA Kinney. 2012. "Uptake of Human Pharmaceuticals and Personal Care Products by Cabbage (Brassica Campestris) from Fortified and Biosolids-Amended Soils." *Journal of Environmental Monitoring* 14 (11) (November): 3029–36. http://www.ncbi.nlm.nih.gov/pubmed/23051741

Holzem, RM, Stapleton, HM, and Gunch, CK. 2014. "Determining the Ecological Impacts of Organic Contaminants in Biosolids Using a High-Throughput Colorimetric Denitrification Assay: A Case Study with Antimicrobial Agents". *Environmental Science and Technology* Feb. 4, 2014.

Jjemba, PK. 2002. "The Potential Impact of Veterinary and Human Therapeutic Agents in Manure and Biosolids on Plants Grown on Arable Land: a Review." *Agriculture, Ecosystems & Environment* 93 (1-3): 267–278. http://linkinghub.elsevier.com/retrieve/pii/S0167880901003504

Karnjanapiboonwong, A, DA Chase, JE Cañas, WA Jackson, JD Maul, AN Morse, and TA Anderson. 2011. "Uptake of 17α-Ethynylestradiol and Triclosan in Pinto Bean, Phaseolus Vulgaris." *Ecotoxicology and Environmental Safety* 74 (5) (July): 1336–42. http://www.ncbi.nlm.nih.gov/pubmed/21513980

Kinney, CA, ET Furlong, DW Kolpin, MR Burkhardt, SD Zaugg, SL Werner, JP Bossio, and MJ Benotti. 2008. "Bioaccumulation of Pharmaceuticals and Other Anthropogenic Waste Indicators in Earthworms from Agricultural Soil Amended with Biosolid or Swine Manure." *Environmental Science Technology* 42 (6): 1863–1870.

Kinney, CA, ET Furlong, SD Zaugg, MR Burkhard, SL Werner, JD Cahill, and GR Jorgensen. 2006. "Survey of Organic Wastewater Contaminants in Biosolids Destined for Land Application." *Environmental Science Technology* 40 (23): 7207–7215. http://www.ncbi.nlm.nih.gov/pubmed/17180968

Kipper, K, K Herodes, M Lillenberg, L Nei, E Haiba, and SV Litvin. 2010. "Plant Uptake of Some Pharmaceuticals Commonly Present in Sewage Sludge Compost." *2nd International Conference on Chemical Biological and Environmental Engineering (ICBEE 2010)*: 261–264.

Kjeldsen, P, MA Barlaz, AP Rooker, A Baun, A Ledin and TH Christensen. 2002. "Present and Long-Term Composition of MSW Landfill Leachate: A Review. *Critical Reviews in Environmental Technology* 32(4):297-336.

Kolpin, DW, ET Furlong, MT Meyer, EM Thurman, SD Zaugg, LB Barber, HT Buxton. 2002. "Pharmaceuticals, hormones, and other organic wastewater contaminants in US streams, 1999-2000: a national reconnaissance. *Environmental Science Technology*, 36: 1202-1211.

Kumar, K, SC Gupta, SK Baidoo, Y Chander, and CJ Rosen. 2005. "Antibiotic Uptake by Plants from Soil Fertilized with Animal Manure." *Journal of Environmental Quality* 34 (6): 2082–2085. http://www.ncbi.nlm.nih.gov/pubmed/16221828

Langdon, KA, M St J Warne, RJ Smernik, A Shareef, and RS Kookana. 2012. "Field Dissipation of 4-Nonylphenol, 4-t-Octylphenol, Triclosan and Bisphenol A Following Land Application of Biosolids." *Chemosphere* 86 (10) (March): 1050–8. http://www.ncbi.nlm.nih.gov/pubmed/22196087

Lapen, DR, E Topp, CD Metcalfe, H Li, M Edwards, N Gottschall, P Bolton, W Curnoe, M Payne, A Beck, 2008. "Pharmaceutical and personal care products in tile drainage following land application of liquid municipal biosolids". *Science of the Total Environment* 399, 50–65.

Leu, S-Y, L Chan, and MK Stenstrom. 2012. "Toward Long Solids Retention Time of Activated Sludge Processes: Benefits in Energy Saving, Effluent Quality, and Stability." *Water Environment Research* 84 (1): 42–53. http://www.ingentaconnect.com/content/wef/wer/2012/00000084/00000001/art00006

Lorber, M. 2008. "Exposure of Americans to polybrominated diphenyl ethers". *Journal of Exposure Science & Environmental Epidemiology* 18(1): 2-19. http://www.ncbi.nlm.nih.gov/pubmed/17426733

Macherius, A, T Eggen, WG Lorenz, T Reemtsma, U Winkler, and M Moeder. 2012. "Uptake of Galaxolide, Tonalide, and Triclosan by Carrot, Barley, and Meadow Fescue Plants." *Journal of Agricultural and Food Chemistry* 60 (32) (August 15): 7785–91. http://www.ncbi.nlm.nih.gov/pubmed/22813076

Macherius, A, T Eggen, W Lorenz, M Moeder, J Ondruschka, and T Reemtsma. 2012. "Metabolization of the Bacteriostatic Agent Triclosan in Edible Plants and Its Consequences for Plant Uptake Assessment." *Environmental Science Technology* 46: 10797–804.

Moss, LH, E Epstein, T Logan, SD Frank and K Scott. 2002. "Evaluating Risks and Benefits of Soil Amendments Used in Agriculture." Water Environment Research Foundation (WERF) Report: 99-PUM-1RD. ISBN: 9781843396512.

National Research Council (NRC). 1996. *Use of Reclaimed Water and Sludge in Food Crop Production*, Washington DC: National Academy Press. http://www.nap.edu/catalog.php?record_id=5175

National Research Council (NRC). 2002. "Biosolids Applied to Land: Advancing Standards and Practices." Washington, DC: The National Academies Press. http://www.casaweb.org/documents/2014/2002-national-academy-of-science-biosolids_report.pdf

North East Biosolids and Residuals Associateion (NEBRA). 2007. A National Biosolids Regulation, Quality, End Use and Disposal Survey. Final Report. July 20, 2007.

Overcash, M and D Pal. 1979. Design of land treatment systems for industrial wastes. Ann Arbor Sci., Ann Arbor, MI.

Overcash, M, RC Sims, JL Sims, and JKC Nieman. 2005. "Beneficial Reuse and Sustainability: The Fate of Organic Compounds in Land-Applied Waste." *Journal of Environmental Quality* 34 (1): 29–41. http://www.ncbi.nlm.nih.gov/pubmed/15647532

Pannu, MW, GS Toor, GA O'Connor, and PC Wilson. 2012. "Toxicity and Bioaccumulation of Biosolids-Borne Triclosan in Food Crops." *Environmental Toxicology and Chemistry / SETAC* 31 (9) (September): 2130–7. http://www.ncbi.nlm.nih.gov/pubmed/22761010

Pepper, IL, H Zerzghi, JP Brooks, and CP Gerba. 2008. "Sustainability of Land Application of Class B Biosolids." *Journal of Environmental Quality* 37 (5 Suppl): S58–67. http://www.ncbi.nlm.nih.gov/pubmed/18765778

Pepper, IL, JP Brooks, RG Sinclair, PL Gurian, CP Gerba. 2010. Pathogens and Indicators in United States Class B Biosolids: National and Historic Distributions. *Journal of Environmental Quality* 39: 2185-2190.

Phillips, P & A Chalmers. 2009. "Wastewater Effluent, Combined Sewer Overflows, and Other Sources of Organic Compounds to Lake Champlain." *Journal of the American Water Resources Association*, *45*(1), 45–57.

Phillips, PJ, AT Chalmers., JL Gray, DW Kolpin, WT Foreman, & GR Wall. 2012. "Combined Sewer Over flows: An Environmental Source of Hormones and Wastewater Micropollutants." *Environmental Science and Technology* 46: 5336-5343.

Rideout, K, and K Teschke. 2004. "Potential for Increased Human Foodborne Exposure to PCDD/F When Recycling Sewage Sludge on Agricultural Land." *Environmental Health Perspectives* 112 (9) (April 26): 959–969. http://www.ehponline.org/ambra-doi-resolver/10.1289/ehp.6802

Roberts, P., JP Roberts, and DL Jones. 2006. "Behaviour of the Endocrine Disrupting Chemical Nonylphenol in Soil: Assessing the Risk Associated with Spreading Contaminated Waste to Land." *Soil Biology and Biochemistry* 38 (7) (July): 1812–1822. http://linkinghub.elsevier.com/retrieve/pii/S0038071706000599

Roccaro P., Vagliasindi, F. 2014. " Risk Assessment of the Use of Biosolids Containing Emerging Organic Contaminants in Agriculture." *Chemical Engineering Transactions* Vol. 37, p. 817 http://www.aidic.it/cet/14/37/137.pdf

Rossi-Marshall, D, DW Kincaid, HA Bechtold, TV Royer, M Rojas, JJ Kelly. 2013. "Pharmaceuticals suppress algal growth and microbial respiration and alter bacterial communities in stream biofilms." *Ecological Applications* 23(3): 583-593.

Rusin, PA, SL Maxwell, JP Brooks, CP Gerba, IL Pepper. 2003. "Evidence for the absence of *Staphylococcus aureus* in land applied biosolids." *Environmental Science & Technology* 37(18): 4027-30.http://www.ncbi.nlm.nih.gov/pubmed/14524431

Ryan, JA, WR Berti, SL Brown, SW Casteel, RL Chaney, M Doolan, P Grevatt, JG Hallfrisch, M Maddaloni, D Mosby. 2004. "Reducing children's risk to soil lead: summary of a field experiment." *Journal of Environmental Science and Technology* 38(1):18A-24A.

Sabourin, L, A Beck, PW Duenk, S Kleywegt, DR Lapen, H Li, CD Metcalfe, M Payne, and E Topp. 2009. "Runoff of Pharmaceuticals and Personal Care Products Following Application of Dewatered Municipal Biosolids to an Agricultural Field." *Science of the Total Environment* 407: 4596–4604.

Sabourin, L, P Duenk, S Bonte-Gelok, M Payne, DR Lapen, and E Topp. 2012. "Uptake of Pharmaceuticals, Hormones and Parabens into Vegetables Grown in Soil Fertilized with Municipal Biosolids." *The Science of the Total Environment* 431 (August 1): 233–6. http://www.ncbi.nlm.nih.gov/pubmed/22687432

Scandura and Sobsey. 1997. "Viral and bacterial contamination of groundwater from on-site sewage treatment systems". *Water Science & Technology* 35(11-12): 141-146. http://www.sciencedirect.com/science/article/pii/S0273122397002497

Schiffman, SS, JM Walker, P Dalton, TS Lorig, JH Raymer, D Shusterman and CM Williams. 2004. "Potential Health Effects of Odor from Animal Operations, Wastewater Treatment, and Recycling of Byproducts." *Journal of Agromedicine* 9(2): 397-403.

Snyder, EH, and GA O'Connor. 2013. "Risk Assessment of Land-Applied Biosolids-Borne Triclocarban (TCC)." *The Science of the Total Environment* 442 (January 1): 437–44. http://www.ncbi.nlm.nih.gov/pubmed/23183124

Snyder, ElH, GA O'Connor, and DC McAvoy. 2011. "Toxicity and Bioaccumulation of Biosolids-Borne Triclocarban (TCC) in Terrestrial Organisms." *Chemosphere* 82 (3) (January): 460–7. http://www.ncbi.nlm.nih.gov/pubmed/21035164

Southworth, RM. 1995. "The Part 503 Land Application Pollutant Limits for Arsenic." U.S. Environmental Protection Agency, Washington, DC. http://www.casaweb.org/documents/2011/part-503-land-application-limits-arsenic.pdf

Specter, M. (1992, June 29). Ocean Dumping Is Ending, but Not Problems; New York Can't Ship, Bury or Burn Its Sludge, but No One Wants a Processing Plant. *New York Times*. Retrieved from: http://www.nytimes.com/1992/06/29/nyregion/ocean-dumping-ending-but-not-problems-new-york-can-t-ship-bury-burn-its-sludge.html?pagewanted=all&src=pm

Trapp, S, and T Eggen. 2013. "Simulation of the Plant Uptake of Organophosphates and Other Emerging Pollutants for Greenhouse Experiments and Field Conditions." *Environmental Science and Pollution Research International* 20 (6) (June): 4018–29. http://www.ncbi.nlm.nih.gov/pubmed/23212267

U.N. - Human Settlements Programme and Greater Moncton Sewerage Commission. 2008. "Global Atlas of Excretia, Wastewater Sludge, and Biosolids Management: Moving Forward the Sustainable and Welcome Uses of a Global Resource." http://esa.un.org/iys/docs/san_lib_docs/habitat2008.pdf

U.S. Census Bureau, Housing and Household Economic Statistics Division, Last Revised: October 31, 2011. http://www.census.gov/hhes/www/housing/census/historic/sewage.html

U.S. Department of Agriculture (USDA). 2009. 2007 Census of agriculture. AC-07-A-51. Volume 1. USDA, National Agricultural Statistics Service. Geographic Area Series, Washington, DC. http://www.agcensus.usda.gov/Publications/2007/Full_Report/usv1.pdf

U.S. Environmental Protection Agency (EPA). 1993. Standards for the Use or Disposal of Sewage Sludge Title 40 of the Code of Federal Regulations (CFR) Part 503. http://yosemite.epa.gov/r10/water.nsf/NPDES+Permits/Sewage+S825/$FILE/503-032007.pdf

U.S. Environmental Protection Agency (EPA). 1994. *A Plain English Guide to the EPA Part 503 Biosolids*, Washington, DC: USEPA Office of Wastewater Management. EPA-832-R-93-003 http://water.epa.gov/scitech/wastetech/biosolids/503pe_index.cfm

U.S. Environmental Protection Agency (EPA). 1995. A Guide to the Biosolids Risk Assessments for the EPA Part 503 Rule, Washington, DC: USEPA Office of Wastewater Management. EPA-832-B-93-005. http://water.epa.gov/scitech/wastetech/biosolids/503rule_index.cfm

U.S. Environmental Protection Agency (EPA). 2003. EPA Makes Final Decision on Dioxin in Sewage Sludge used in Land Applications. Press Release, 10/17/2003. http://yosemite.epa.gov/opa/admpress.nsf/b1ab9f485b098972852562e7004dc686/209dab87e1b0a8b785256dc20050c977?OpenDocument

U.S. Environmental Protection Agency (EPA). 2003b. December 24, 2003 letter to Joseph Mendelson, III, Legal Director, Center for Food Safety regarding Petition Seeking an Emergency Moratorium on the Land Application of Sewage Sludge, dated October 7, 2003 from G. Tracy Mehan, III, Assistant Administrator, EPA Office of Water, Washington DC.

U.S. Environmental Protection Agency (EPA). 2009. Occurrence of Contaminants of Emerging Concern in Wastewater From Nine Publically Owned Treatment Works. August 2009. EPA-821-R-09-009.

U.S. Environmental Protection Agency (EPA). 2009b. Targeted National Sewage Sludge Survey Sampling and Analysis Technical Report. January 2009. EPA-822-R-08-016.

U.S. Environmental Protection Agency (EPA). 2010. Treating Contaminants of Emerging Concern -A Literature Review Database. August 2010. EPA-820-R-10-002.

U.S. Environmental Protection Agency (EPA). 2012. Water: Sewage Sludge (Biosolids), Frequently Asked Questions. http://water.epa.gov/polwaste/wastewater/treatment/biosolids/genqa.cfm

U.S. Environmental Protection Agency (EPA). 2013. Literature Review of Contaminants in Livestock and Poultry Manure and Implications for Water Quality. Office of Water (4304T). EPA 820-R-13-002. July 2013. http://water.epa.gov/scitech/cec/upload/Literature-Review-of-Contaminants-in-Livestock-and-Poultry-Manure-and-Implications-for-Water-Quality.pdf

Viau, E, K Bibby, T Paez-Rubio, and J Peccia. 2011. "Toward a Consensus View on the Infectious Risks Associated with Land Application of Sewage Sludge." *Environmental Science & Technology* 45 (13) (July 1): 5459–69. doi:10.1021/es200566f. http://www.ncbi.nlm.nih.gov/pubmed/21644497

Vermont Public Interest Research Group (VPIRG). June 1999. "On the Ground" http://www.vpirg.org/download/1999%20June%20Toxic%20Sludge%20report.pdf

Water Environment Federation (WEF). 2004. History of Biosolids. Fact Sheet. http://www.wef.org/Biosolids/page.aspx?id=7514&ekmensel=c57dfa7b_123_0_7514_2

Wild, SR, SJ Harrad, and KC Jones. 1994. "The Influence of Sewage Sludge Applications to Agricultural Land on Human Exposure to Polychlorinated Dibenzo-p-Dioxins (PCDDs) and -Furans (PCDFs)." *Environmental Pollution (Barking, Essex : 1987)* 83 (3) (January): 357–69. http://www.ncbi.nlm.nih.gov/pubmed/15091742

Wong, K, T Harrigan, and I Xagoraraki. 2012. "Leaching and Ponding of Viral Contaminants Following Land Application of Biosolids on Sandy-Loam Soil." *Journal of Environmental Management* 112 (December 15): 79–86. http://www.ncbi.nlm.nih.gov/pubmed/22885066

Wu, C, AL Spongberg, JD Witter, MFang, and KP Czajkowski. 2010. "Uptake of Pharmaceutical and Personal Care Products by Soybean Plants from Soils Applied with Biosolids and Irrigated with Contaminated Water." *Environmental Science Technology* 44 (16): 6157–6161. http://www.ncbi.nlm.nih.gov/pubmed/20704212

Wu, C, AL Spongberg, JD Witter, and BB Maruthi Sridhar. 2012. "Transfer of Wastewater Associated Pharmaceuticals and Personal Care Products to Crop Plants from Biosolids Treated Soil." *Ecotoxicology and Environmental Safety* 85 (November): 104–9. http://www.ncbi.nlm.nih.gov/pubmed/22921256

Yager, TJB, ET Furlong, DW Kolpin, CA Kinney, SD Zaugg, MR Burkhardt. 2014. "Dissipation of Contaminants of Emerging Concern in Biosolids Applied to Nonirrigated Farmland in Eastern Colorado". *Journal of the American Water Resource Association* 50(2): 343-357.

Yang, Y-Y, JL Gray, ET Furlong, JG Davis, RC Revello, and T Borch. 2012. "Steroid Hormone Runoff from Agricultural Test Plots Applied with Municipal Biosolids." *Environmental Science & Technology* 46 (5) (March 6): 2746–54. http://www.ncbi.nlm.nih.gov/pubmed/22283735

Appendix 1: Description of Highly Exposed Individuals (HEIs)

The 1989 proposed Part 503 rule considered the exposed individual to be a "most exposed individual" (MEI). EPA changed the exposed individual from the MEI to the HEI so that the final rule would be consistent with a statement in the rule's legislative history that calls for protecting individuals and populations that are "highly exposed to reasonably anticipated adverse conditions." In developing Subpart B of the rule, EPA used different HEIs in evaluating each pathway of potential exposure from the toxic effects of pollutants in land-applied sewage sludge.

For agricultural settings for Pathway 1, which is designed to protect consumers who eat produce grown in sewage sludge-amended soil, the HEI is assumed to live in a region where a relatively high percentage of the available cropland receives sludge applications. Although all vegetables in the diet could be presumed to be affected, this assumption was considered to be too severe a worst case. Instead it was assumed that the HEI ingests a mix of crops from land on which sludge was applied as well as from land on which sludge was not applied.

For nonagricultural settings for Pathway 1, the HEI is a person who regularly harvests edible wild plants (i.e., berries and mushrooms) from forests or range lands that have been amended with sewage sludge. This food is preserved by drying, freezing, or canning and is, hence, available for consumption throughout the year. It is also assumed that an individual could continue with this practice for a lifetime, estimated as 70 years.

Pathway 2 evaluates the effects to home gardeners from consuming crops grown in residential home gardens that have been amended with sewage sludge. The major difference between Pathways 1 and 2 is the fraction of food assumed to be grown on sewage sludge-amended soil. The HEI for Pathway 2 is the home gardener who produces and consumes potatoes, leafy vegetables, fresh legumes, root vegetables, garden fruits (e.g., tomatoes, eggplants), sweet corn, and grains. (These are also consumed but not produced by the HEI in Pathway 1.) Unlike Pathway 1, peanuts and dried legumes are not included, because the HEI in Pathway 2 is unlikely to grow them in residential settings.

The HEI for Pathway 3, which assesses the hazard to a child from ingesting undiluted sewage sludge, is a child ingesting sewage sludge from storage piles or from the soil surface. For the residential setting, this HEI is assumed to be a child between the ages of 1 and 6. In the

5-4

nonagricultural setting, it is unlikely that a child younger than 4 years old would be unattended for a long enough time to ingest the sludge. The HEI for the nonagricultural setting is therefore assumed to be exposed for 2 years between the ages of 4 and 6.

The HEI for Pathway 4 is an individual consuming foraging animals that consumed feed crops or vegetation grown on sewage sludge-amended soils. The HEI is assumed to consume daily quantities of the various animal tissue foods and to be exposed to background levels of pollutants from sources other than sludge. For the agricultural setting, the affected animal foods evaluated were beef, beef liver, lamb, pork, poultry, dairy, and eggs.

In the nonagricultural setting, the HEI for this pathway is assumed to be a hunter who preserves meat (including liver) for consumption through the year. The animals hunted in the forest and eaten are assumed to be deer and elk. Although other animals could be hunted and consumed, the Agency evaluated only these large mammals because their greater size makes them capable of having a more significant impact on the total human diet.

Pathway 5 involves the application of sewage sludge to the land, the direct ingestion of this sewage sludge by animals, and, finally, the consumption of contaminated animal tissue by humans. The HEI is assumed to consume various animal tissue foods and is also assumed to be exposed to a background intake of pollutants.

Pathway 6 evaluates animals that ingest plants grown on sewage sludge-amended soil. The HEI for both agricultural and nonagricultural uses is a highly sensitive herbivore that consumes plants grown on sewage sludge-amended soil. Background intake is taken into account by considering background concentration of pollutants in forage crops. In a forest application site there are two HEIs: domestic animals that graze, and small herbivorous mammals such as deer mice that live their entire lives in a sewage sludge-amended area feeding on seeds and small plants close to the layer of soil amended with sewage sludge. In the agricultural setting, the HEI is a larger grazing mammal, such as a sheep.

The HEI for Pathway 7 is an herbivorous animal that incidentally consumes sewage sludge adhering to forage crops and/or sewage sludge on the soil surface. Background intake is

considered to be from ingesting soil having background levels of pollutant. Since forest animals more typically browse rather than graze, the HEI for agricultural settings is used as a reasonable worst-case surrogate for the nonagricultural HEI.

Pathway 8, the plant phytotoxicity pathway, assumes for its HEI a plant sensitive to the pollutants in sewage sludge. The literature search carried out for this pathway included information on nonagronomic species, which were shown to be no more sensitive than agronomic species. Therefore, the limits set for agricultural species also protect wild species found in nonagricultural settings.

The HEI for Pathway 9 is a soil organism sensitive to the pollutants in sewage sludge—an earthworm. Since all soil organisms are wild species, the same HEI is used for the agricultural as well as the nonagricultural settings.

The HEI for Pathway 10, the soil organism-predator pathway, is wildlife—the shrew mole--that consumes soil organisms that have been feeding on sewage sludge-amended soil. As with Pathway 9, the same HEI is used for both the nonagricultural and agricultural pathways.

Pathway 11, which protects humans from the effects of airborne dusts containing sewage sludge, has as its HEI a tractor driver tilling a field. This pathway evaluates the impact of particles that have been resuspended by the driver's tilling dewatered sewage sludge into the soil. This pathway applies only to the agricultural setting, since tractors are not usually found in nonagricultural settings such as forests.

Pathway 12, the soil erosion pathway, has as an HEI a human who consumes 2 liters/day of drinking water from surface water contaminated by soil eroded from a site where sewage sludge has been land-applied and who ingests 0.04 kg/day of fish from surface waters contaminated by sewage sludge pollutants. The HEI is the same for agricultural and nonagricultural practices.

The HEI for Pathway 13 is a human who inhales the vapors of any volatile pollutants that may be in the sewage sludge when it is applied to the land. The wind direction is assumed never

to change, so that the HEI is assumed to live at the downwind edge of the site. The same plume model was used for both the agricultural and nonagricultural settings.

The HEI for Pathway 14 for agricultural and nonagricultural settings is an individual who obtains his or her drinking water from ground water located directly below a field to which sewage sludge has been applied.

5.1.2.2 Decisions Related to Calculating the Human Dose

5.1.2.2.1 Oral Reference Dose (RfD)

An oral reference dose (RfD) of a pollutant is a threshold below which effects adverse to human health are unlikely to occur. Where the Agency has not published human health criteria for a noncarcinogenic pollutant, the RfD listed in EPA's computerized Integrated Risk Information System (IRIS) was used (U.S. EPA, 1992h). The RfDs listed in IRIS are based on a process within the Agency that includes review of the latest scientific information.

5.1.2.2.2 Recommended Dietary Allowances (RDAs)

RDAs are defined as the levels of intake of essential nutrients that, on the basis of scientific knowledge, are judged by the Food and Nutrition Board to be adequate to meet the known nutrient needs of practically all healthy persons (NAS, 1989). Although RfDs were used to determine the concentrations of inorganic pollutants that are protective of human health, the RDA was used in two cases: zinc and copper. Since there is at present no Agency-approved RfD for copper, the RDA was used as a reasonably protective dose. In the case of zinc, the Agency has established an RfD, but that value is insufficient to meet the daily nutritional requirements of the exposed population. The Agency therefore chose to use the higher RDA value.

APPENDIX 2: Landfill leachate

Table A-1: Xenobiotic organic compounds in landfill leachates (Kjeldsen et al. 2002)

Compound	Concentration Range (µg/L)
Aromatic hydrocarbons	
benzene	0.2 - 1630
toluene	1 - 12300
xylene	0.8 - 3500
ehtylbenzene	0.223
trimethylbenzenes	0.3 - 250
n-propylbenzene	0.3 - 16
t-butylbenzene	2.1 - 21
o-ethyltoluene	0.5 - 46
m-ethyltoluene	0.3 - 21
p-ethyltoluene	0.2 - 10
naphthalene	0.1 - 260
Halogenated hydrocarbons	
chlorobenzene	0.1 - 110
1,2-dichlorobenzene	0.1 - 32
1,3-dichlorobenzene	5.4 - 19
1,4-dichlorobenzene	0.1 - 26
1,2,3-trichlorobenzene	BQL
1,2,4-trichlorobenzene	4.3
hexachlorobenzene	0.025 - 10
1,1-dichloroethane	0.6 - 46
1,2-dichloroethane	<6
1,1,1-trichloroethane	0.1 - 3810
1,1,2-trichloroethane	2.5 - 16
1,1,2,2-tetrachloroethane	BQL
trans-1,2-dichloroethylene	1.6 - 6582
cis-1,2-dichloroethylene	1.4 - 470
trichloroethylene	0.5 - 750
tetrachloroethylene	0.1 - 250
dichloromethane	1 - 827
trichloromethane	1 - 70
carbontetrachloride	4 - 9
Phenols	
phenol	0.6 - 1200
ethylphenols	<300
cresols	1 - 2100
bisphenol A	200 - 400
3,5-dimethylphenol	0.7 - 27.3
2,5-dimethylphenol	0.4 - 4.5
2,4-dimethyphenol	0.1 - 12.5
3,4-dimethylphenol	0.03 - 10.4
2,6-dimethylphenol	0.3 - 1.9
2-methoxyphenol	BQL

Table A-1 (Continued):

2,3-dichlorophenol	0.03 - 1.6
4-chlorophenol	0.2 - 1.3
4-chloro-m-cresol	1.2 - 10.2
3,5-dichlorophenol	0.08 - 0.63
2,3,4,6-tetrachlorophenol	0.079 - 3
Alkylphenols	
nonylphenol	6.3 - 7
nonylphenol monocarboxylate	0.5 - 3
Pesticides	
Ametryn	0.12
AMPA	3.8 - 4.3
Atrazine	0.16
Bentazon	0.3 - 4
Chloridazon	1.6
Chlorpropham	26
Dichlobenil	0.1 - 0.3
Fenpropimor	0.1
Glyphosphate	1.7 - 27
Hexazinon	1.3
Hydroxyatrizine	0.7 - 1.7
Hydroxysimazin	0.6 - 1.7
Isoproturon	1.2
Lindane	0.025 - 0.95
Mecoprop	0.38 - 150
MCPA	0.2 - 9.1
Propaxuron	2.6
Simazine	2.3
Tridimefon	2.1
4-CPP	15 - 19
2,4-D	1.0 - 5
2,4,5-T	BQL
2,4-DP	0.3 - 5.2
2,6-DCPP	0.7 - 1.3
Phthalates	
monomethyl phthalate	1
dimethyl phthalate	0.1 - 7.7
diethyl phthalate	0.1 - 660
methyl-ethyl phthalate	20 - 340
mono-(2-ethylhexyl) phthalate	4 - 14
di-(2-ethylhexyl) phthalate	0.6 - 236
monobutyl phthalate	4 - 16
di-n-butyl phthalate	0.1 - 70
di-isobutyl phthalate	3 - 6
mono-benzyl phthalate	6 - 16
butylbenzyl phthalate	0.8 - 8
dioctyl phthalate	1 - 6

phthalic acid	2 - 14000

Table A-1 (Continued):

Aromatic sulfonates	
naphthalene-1-sulfonate	506 - 616
naphthalene-2-sulfonate	1143 - 1188
naphthalene-1,5-disulfonate	2.5 - 51
naphthalene-1,6-disulfonate	366 - 397
naphthalene-2,7-disulfonate	129-145
2-aminonapthalene-4,8-disulfonate	73-109
p-toluenesulfonate	704-1084
Phosphonates	
tri-n-butylphosphate	1.2 - 360
triethylphosphate	15
Miscellaneous	
acetone	6 - 4400
2(3H)-benzothiazolone	10 - 50
camphor	20.6 - 255.2
cumen	0.3 - 7.4
fenchone	7.3 - 83
tetrahydrofuran	9 - 430
indane	0.2 - 20
methylethylketone	110 - 6600
methyl-isobutylketone	1.1 - 176
dimethoxymethane	1.1
MTBE	0.8 - 35
styrene	0.5 - 1.6

BQL = detected below quantification limit

Table A-2: Concentration of selected contaminants in leachate from a Vermont landfill (National Landfill Leachate Study, USGS, June 2012)

Compound	Concentration (µg/L)
10-hydroxy-amitriptyline	0.86
19-norethindrone	0.68
abacavir	BDL
acetaminophen	59.12
aciclovir	13.27
albuterol	0.12
alprazolam	BDL
amitriptyline	BDL
amphetamine	6.26
antipyrene	1.98
atenolol	4.57
atrazine	1.08
benzotriazole methyl-1H	11.77
benztropine	BDL
betamethasone	BDL
bupropion	BDL
caffeine	2.74
carbamazepine	2.18
carisoprodol	2.94
chlorpheniramine	0.09
cimetidine	2.92
cis-diltiazem	BDL
citalopram	BDL
clonidine	BDL
cocaine	BDL
codeine	0.28
cotinine	43.32
dehydronifedipine	1.30
delta9tetrahydrocannabinol	BDL
desvenlafaxine	2.61
dextromethorphan	0.08
diazepam	BDL
diphenhydramine	0.08
duloxetine	BDL
erythromycin	0.09
esomeprazole	BDL
ezetimibe	BDL
fadrozole	0.38
famotidine	BDL
fenofibrate	BDL
fexofenadine	0.48
fluconazole	2.49
fluoxetine	BDL
fluticasone	BDL
fluvoxamine	0.08
glipizide	BDL
glyburide	BDL
hydrocodone	BDL
hydrocodone-D3	0.08

Table A-2 (Continued):

hydrocortisone	BDL
hydroxyzine	BDL
iminostilbene	BDL
ketoconazole	BDL
lamivudine	0.47
lidocaine	128.63
loperamide	BDL
loratadine	0.08
lorazepam	25.68
meprobamate	1.12
metaxalone	0.76
metformin	0.91
methadone	BDL
methocarbamol	2.35
methotrexate	BDL
metoprolol	1.31
morphine	0.38
nadolol	1.15
N-desmethyldiltiazem	0.26
nevirapine	BDL
nicotine	194.45
nizatidine	BDL
nordiazepam	BDL
norfluoxetine	BDL
norfluoxetine-D6	0.09
norverapamil	BDL
orlistat	BDL
oseltamivir	0.17
oxazepam	3.59
oxycodone	BDL
paraxanthine	1.59
paroxetine	BDL
penciclovir	1.54
pentoxyfylline	1.03
phenazopyridine	BDL
phendimetrazine	0.48
phenytoin	5.14
piperonylbutoxide	0.09
prednisolone	23.02
prednisone	BDL
promethazine	BDL
propanolol	BDL
propoxyphene	BDL
pseudoephederine	40.86
quinine	BDL
rac-cis-N-desmethylsertraline	BDL
raloxifene	25.59
ranitidine	0.34
sertraline	BDL
sitagliptin	BDL
sulfadimethoxine	85.53

Table A-2 (Continued):

sulfamethizole	BDL
sulfamethoxazole	BDL
tamoxifen	BDL
temazepam	BDL
theophylline	1.71
thiabendazole	1.62
tiotropium	BDL
tramadol	1.75
triamterene	0.07
trimethoprim	BDL
valacyclovir	0.48
venlafaxine	1.72
verapamil	BDL
warfarin	0.12

BDL = below detection limit

Table A-3: Concentration of selected parameters in leachate from a Vermont landfill (DEC Wastewater Management Program Compliance Files, 2014)

Laboratory Report DATE REPORTED: 02/26/2014

CLIENT: [redacted]
PROJECT:

WORK ORDER: **1402-02249**
DATE RECEIVED: 02/06/2014

001 Site: Combined AST Date Sampled: 2/6/14 Time: 9:05

Parameter	Result	Units	Method	Analysis Date/Time	Lab/Tech	NELAC	Qual.
BOD-5day	2,100	mg/L	SM20 5210B	2/6/14 16:06	W JSS	A	
Chloride	1,700	mg/L	EPA 300.0	2/7/14	W CM	A	
COD	4900	mg/L	Hach 8000	2/21/14	N JGM	A	
TKN	990	mg/L	EPA 351.2	2/18/14	N CAL	A	
Arsenic, Total	0.41	mg/L	EPA 200.7	2/13/14	W RGT	N	
Cadmium, Total	< 0.008	mg/L	EPA 200.7	2/13/14	W RGT	A	
Chromium, Total	0.23	mg/L	EPA 200.7	2/13/14	W RGT	A	
Copper, Total	< 0.080	mg/L	EPA 200.7	2/13/14	W RGT	A	
Lead, Total	< 0.080	mg/L	EPA 200.7	2/13/14	W RGT	N	
Mercury, Total	< 0.0002	mg/L	EPA 245.1	2/11/14	W CM	A	
Molybdenum, Total	< 0.080	mg/L	EPA 200.7	2/13/14	W RGT	A	
Nickel, Total	0.42	mg/L	EPA 200.7	2/13/14	W RGT	A	
Selenium, Total	< 0.004	mg/L	SM20 3113B	2/18/14	W AWM	A	
Sodium, Total	1280	mg/L	EPA 200.7	2/13/14	W RGT	A	
Zinc, Total	1.3	mg/L	EPA 200.7	2/13/14	W RGT	A	
Volatile Organic Compounds							
Dichlorodifluoromethane	< 100	ug/L	EPA 8260C	2/18/14	W MHM	A	
Chloromethane	< 60.0	ug/L	EPA 8260C	2/18/14	W MHM	N	
Vinyl chloride	< 40.0	ug/L	EPA 8260C	2/18/14	W MHM	A	
Bromomethane	< 100	ug/L	EPA 8260C	2/18/14	W MHM	A	
Chloroethane	< 100	ug/L	EPA 8260C	2/18/14	W MHM	A	
Trichlorofluoromethane	< 40.0	ug/L	EPA 8260C	2/18/14	W MHM	A	
Diethyl ether	< 100	ug/L	EPA 8260C	2/18/14	W MHM	N	
1,1-Dichloroethene	< 20.0	ug/L	EPA 8260C	2/18/14	W MHM	A	
Acetone	4,870	ug/L	EPA 8260C	2/18/14	W MHM	A	
Carbon disulfide	< 100	ug/L	EPA 8260C	2/18/14	W MHM	A	
Methylene chloride	< 100	ug/L	EPA 8260C	2/18/14	W MHM	A	
t-Butanol	1,700	ug/L	EPA 8260C	2/18/14	W MHM	N	QA-
Methyl-t-butyl ether (MTBE)	< 40.0	ug/L	EPA 8260C	2/18/14	W MHM	A	
trans-1,2-Dichloroethene	< 20.0	ug/L	EPA 8260C	2/18/14	W MHM	A	
Di-isopropyl ether (DIPE)	< 40.0	ug/L	EPA 8260C	2/18/14	W MHM	N	
1,1-Dichloroethane	< 20.0	ug/L	EPA 8260C	2/18/14	W MHM	A	
Ethyl-t-butyl ether (ETBE)	< 40.0	ug/L	EPA 8260C	2/18/14	W MHM	N	
2-Butanone	5,760	ug/L	EPA 8260C	2/18/14	W MHM	A	
2,2-Dichloropropane	< 40.0	ug/L	EPA 8260C	2/18/14	W MHM	N	
cis-1,2-Dichloroethene	< 20.0	ug/L	EPA 8260C	2/18/14	W MHM	N	
Bromochloromethane	< 40.0	ug/L	EPA 8260C	2/18/14	W MHM	N	
Chloroform	< 20.0	ug/L	EPA 8260C	2/18/14	W MHM	A	
Tetrahydrofuran	2,620	ug/L	EPA 8260C	2/18/14	W MHM	U	
1,1,1-Trichloroethane	< 20.0	ug/L	EPA 8260C	2/18/14	W MHM	A	
Carbon tetrachloride	< 20.0	ug/L	EPA 8260C	2/18/14	W MHM	A	
1,1-Dichloropropene	< 20.0	ug/L	EPA 8260C	2/18/14	W MHM	N	
Benzene	< 20.0	ug/L	EPA 8260C	2/18/14	W MHM	A	
t-Amylmethyl ether (TAME)	< 40.0	ug/L	EPA 8260C	2/18/14	W MHM	N	
1,2-Dichloroethane	< 20.0	ug/L	EPA 8260C	2/18/14	W MHM	A	
Trichloroethene	< 20.0	ug/L	EPA 8260C	2/18/14	W MHM	A	

ENDYNE Inc.
www.endynelabs.com

Table A-3 (continued):

Laboratory Report DATE REPORTED: 02/26/2014

CLIENT: [redacted]
PROJECT:

WORK ORDER: **1402-02249**
DATE RECEIVED: 02/06/2014

001 Site: Combined AST Date Sampled: 2/6/14 Time: 9:05

Parameter	Result	Units	Method	Analysis Date/Time	Lab/Tech	NELAC	Qual.
1,2-Dichloropropane	< 40.0	ug/L	EPA 8260C	2/18/14	W MHM	A	
Dibromomethane	< 40.0	ug/L	EPA 8260C	2/18/14	W MHM	N	
Bromodichloromethane	< 10.0	ug/L	EPA 8260C	2/18/14	W MHM	A	
cis-1,3-Dichloropropene	< 20.0	ug/L	EPA 8260C	2/18/14	W MHM	A	
4-Methyl-2-pentanone (MIBK)	< 200	ug/L	EPA 8260C	2/18/14	W MHM	N	
Toluene	25.4	ug/L	EPA 8260C	2/18/14	W MHM	A	
trans-1,3-Dichloropropene	< 40.0	ug/L	EPA 8260C	2/18/14	W MHM	A	
1,1,2-Trichloroethane	< 20.0	ug/L	EPA 8260C	2/18/14	W MHM	A	
Tetrachloroethene	< 20.0	ug/L	EPA 8260C	2/18/14	W MHM	A	
1,3-Dichloropropane	< 20.0	ug/L	EPA 8260C	2/18/14	W MHM	N	
2-Hexanone	< 200	ug/L	EPA 8260C	2/18/14	W MHM	N	
Dibromochloromethane	< 40.0	ug/L	EPA 8260C	2/18/14	W MHM	A	
1,2-Dibromoethane	< 20.0	ug/L	EPA 8260C	2/18/14	W MHM	A	
Chlorobenzene	< 20.0	ug/L	EPA 8260C	2/18/14	W MHM	A	
Ethylbenzene	< 20.0	ug/L	EPA 8260C	2/18/14	W MHM	A	
1,1,1,2-Tetrachloroethane	< 40.0	ug/L	EPA 8260C	2/18/14	W MHM	A	
Xylenes, Total	< 40.0	ug/L	EPA 8260C	2/18/14	W MHM	A	
Styrene	< 20.0	ug/L	EPA 8260C	2/18/14	W MHM	N	
Bromoform	< 40.0	ug/L	EPA 8260C	2/18/14	W MHM	A	
Isopropylbenzene	< 20.0	ug/L	EPA 8260C	2/18/14	W MHM	A	
1,1,2,2-Tetrachloroethane	< 40.0	ug/L	EPA 8260C	2/18/14	W MHM	A	
Bromobenzene	< 20.0	ug/L	EPA 8260C	2/18/14	W MHM	N	
n-Propylbenzene	< 20.0	ug/L	EPA 8260C	2/18/14	W MHM	A	
1,2,3-Trichloropropane	< 40.0	ug/L	EPA 8260C	2/18/14	W MHM	N	
2-Chlorotoluene	< 20.0	ug/L	EPA 8260C	2/18/14	W MHM	N	
1,3,5-Trimethylbenzene	< 20.0	ug/L	EPA 8260C	2/18/14	W MHM	A	
4-Chlorotoluene	< 20.0	ug/L	EPA 8260C	2/18/14	W MHM	N	
t-Butylbenzene	< 20.0	ug/L	EPA 8260C	2/18/14	W MHM	A	
1,2,4-Trimethylbenzene	< 20.0	ug/L	EPA 8260C	2/18/14	W MHM	A	
s-Butylbenzene	< 20.0	ug/L	EPA 8260C	2/18/14	W MHM	N	
4-Isopropyltoluene	< 20.0	ug/L	EPA 8260C	2/18/14	W MHM	A	
1,3-Dichlorobenzene	< 20.0	ug/L	EPA 8260C	2/18/14	W MHM	A	
1,4-Dichlorobenzene	< 20.0	ug/L	EPA 8260C	2/18/14	W MHM	A	
n-Butylbenzene	< 40.0	ug/L	EPA 8260C	2/18/14	W MHM	A	
1,2-Dichlorobenzene	< 20.0	ug/L	EPA 8260C	2/18/14	W MHM	A	
1,2-Dibromo-3-Chloropropane	< 40.0	ug/L	EPA 8260C	2/18/14	W MHM	A	
1,2,4-Trichlorobenzene	< 40.0	ug/L	EPA 8260C	2/18/14	W MHM	A	
1,3,5-Trichlorobenzene	< 40.0	ug/L	EPA 8260C	2/18/14	W MHM	N	
Hexachlorobutadiene	< 10.0	ug/L	EPA 8260C	2/18/14	W MHM	N	
Naphthalene	< 40.0	ug/L	EPA 8260C	2/18/14	W MHM	A	
1,2,3-Trichlorobenzene	< 40.0	ug/L	EPA 8260C	2/18/14	W MHM	N	
Surr. 1 (Dibromofluoromethane)	96	%	EPA 8260C	2/18/14	W MHM	N	
Surr. 3 (4-Bromofluorobenzene)	101	%	EPA 8260C	2/18/14	W MHM	N	
Surr. 2 (Toluene d8)	99	%	EPA 8260C	2/18/14	W MHM	N	
Unidentified Peaks	7		EPA 8260C	2/18/14	W MHM	U	
EPA 8270C Semi-VOA							

ENDYNE Inc.
www.endynelabs.com

Table A-3 (continued):

Laboratory Report DATE REPORTED: 02/26/2014

CLIENT: [redacted]
PROJECT:

WORK ORDER: **1402-02249**
DATE RECEIVED: 02/06/2014

001 Site: Combined AST Date Sampled: 2/6/14 Time: 9:05

Parameter	Result	Units	Method	Analysis Date/Time	Lab/Tech	NELAC	Qual.
Extraction EPA 3510C	Extracted		EPA 3510C	2/12/14	W FAA	A	
N-Nitrosodimethylamine	< 200	ug/L	EPA 8270D	2/21/14	W EEP	A	
Pyridine	< 200	ug/L	EPA 8270D	2/21/14	W EEP	A	
Aniline	< 200	ug/L	EPA 8270D	2/21/14	W EEP	N	
Bis(2-chloroethyl)ether	< 100	ug/L	EPA 8270D	2/21/14	W EEP	A	
1,2-Dichlorobenzene	< 40.0	ug/L	EPA 8270D	2/21/14	W EEP	A	
1,3-Dichlorobenzene	< 40.0	ug/L	EPA 8270d	2/21/14	W EEP	A	
1,4-Dichlorobenzene	< 40.0	ug/L	EPA 8270D	2/21/14	W EEP	A	
Benzyl alcohol	< 400	ug/L	EPA 8270D	2/21/14	W EEP	N	
Bis(2-chloroisopropyl)ether	< 200	ug/L	EPA 8270D	2/21/14	W EEP	N	
N-Nitrosodi-n-propylamine	< 200	ug/L	EPA 8270D	2/21/14	W EEP	A	
Hexachloroethane	< 100	ug/L	EPA 8270D	2/21/14	W EEP	A	
Nitrobenzene	< 100	ug/L	EPA 8270D	2/21/14	W EEP	A	
N-Nitrosopiperidine	< 200	ug/L	EPA 8270D	2/21/14	W EEP	N	
Isophorone	< 40.0	ug/L	EPA 8270D	2/21/14	W EEP	A	
Bis(2-chloroethoxy)methane	< 100	ug/L	EPA 8270D	2/21/14	W EEP	A	
1,2,4-Trichlorobenzene	< 40.0	ug/L	EPA 8270D	2/21/14	W EEP	A	
Naphthalene	46.4	ug/L	EPA 8270D	2/21/14	W EEP	A	
4-Chloroaniline	< 100	ug/L	EPA 8270D	2/21/14	W EEP	N	
Hexachlorobutadiene	< 100	ug/L	EPA 8270D	2/21/14	W EEP	A	
N-Nitrosodi-n-butylamine	< 100	ug/L	EPA 8270D	2/21/14	W EEP	N	
2-Methylnaphthalene	< 20.0	ug/L	EPA 8270D	2/21/14	W EEP	A	
1-Methylnaphthalene	< 20.0	ug/L	EPA 8270D	2/21/14	W EEP	U	
Hexachlorocyclopentadiene	< 400	ug/L	EPA 8270D	2/21/14	W EEP	A	
2-Chloronaphthalene	< 40.0	ug/L	EPA 8270D	2/21/14	W EEP	A	
1-Chloronaphthalene	< 40.0	ug/L	EPA 8270D	2/21/14	W EEP	N	
2-Nitroaniline	< 400	ug/L	EPA 8270D	2/21/14	W EEP	N	
Dimethyl phthalate	< 100	ug/L	EPA 8270D	2/21/14	W EEP	A	
2,6-Dinitrotoluene	< 100	ug/L	EPA 8270D	2/21/14	W EEP	A	
Acenaphthylene	< 20.0	ug/L	EPA 8270D	2/21/14	W EEP	A	
3-Nitroaniline	< 100	ug/L	EPA 8270D	2/21/14	W EEP	N	
Acenaphthene	< 20.0	ug/L	EPA 8270D	2/21/14	W EEP	A	
Dibenzofuran	< 40.0	ug/L	EPA 8270D	2/21/14	W EEP	N	
2,4-Dinitrotoluene	< 100	ug/L	EPA 8270D	2/21/14	W EEP	A	
1-Naphthylamine	< 200	ug/L	EPA 8270D	2/21/14	W EEP	N	
2-Naphthylamine	< 200	ug/L	EPA 8270D	2/21/14	W EEP	N	
Fluorene	< 20.0	ug/L	EPA 8270D	2/21/14	W EEP	A	
Diethyl phthalate	< 100	ug/L	EPA 8270D	2/21/14	W EEP	A	
4-Chlorophenyl phenyl ether	< 40.0	ug/L	EPA 8270D	2/21/14	W EEP	A	
4-Nitroaniline	< 400	ug/L	EPA 8270D	2/21/14	W EEP	N	
N-Nitrosodiphenylamine	< 100	ug/L	EPA 8270D	2/21/14	W EEP	A	
Azobenzene	< 100	ug/L	EPA 8270D	2/21/14	W EEP	U	
4-Bromophenyl phenyl ether	< 40.0	ug/L	EPA 8270D	2/21/14	W EEP	A	
Hexachlorobenzene	< 100	ug/L	EPA 8270D	2/21/14	W EEP	A	
Phenanthrene	22.6	ug/L	EPA 8270D	2/21/14	W EEP	N	
Anthracene	< 20.0	ug/L	EPA 8270D	2/21/14	W EEP	A	

ENDYNE Inc.
www.endynelabs.com

Table A-3 (continued):

Laboratory Report DATE REPORTED: 02/26/2014

CLIENT: [redacted]
PROJECT:

WORK ORDER: **1402-02249**
DATE RECEIVED: 02/06/2014

001 Site: Combined AST — Date Sampled: 2/6/14 Time: 9:05

Parameter	Result	Units	Method	Analysis Date/Time	Lab/Tech	NELAC	Qual.
Carbazole	< 100	ug/L	EPA 8270D	2/21/14	W EEP	N	
Di-n-butylphthalate	< 200	ug/L	EPA 8270D	2/21/14	W EEP	A	
Fluoranthene	< 20.0	ug/L	EPA 8270D	2/21/14	W EEP	A	
Benzidine	< 200	ug/L	EPA 8270D	2/21/14	W EEP	A	
Pyrene	< 20.0	ug/L	EPA 8270D	2/21/14	W EEP	A	
Butyl benzyl phthalate	< 100	ug/L	EPA 8270D	2/21/14	W EEP	A	
Benzo(a)anthracene	< 20.0	ug/L	EPA 8270D	2/21/14	W EEP	A	
Chrysene	< 20.0	ug/L	EPA 8270D	2/21/14	W EEP	A	
3,3'-Dichlorobenzidine	< 100	ug/L	EPA 8270D	2/21/14	W EEP	A	
Bis(2-ethylhexyl)phthalate	< 200	ug/L	EPA 8270D	2/21/14	W EEP	A	
Di-n-octylphthalate	< 100	ug/L	EPA 8270D	2/21/14	W EEP	N	
Benzo(b)fluoranthene	< 20.0	ug/L	EPA 8270D	2/21/14	W EEP	A	
Benzo(k)fluoranthene	< 20.0	ug/L	EPA 8270D	2/21/14	W EEP	A	
Benzo(a)pyrene	< 20.0	ug/L	EPA 8270D	2/21/14	W EEP	A	
Indeno(1,2,3-cd)pyrene	< 20.0	ug/L	EPA 8270D	2/21/14	W EEP	A	
Dibenzo(a,h)anthracene	< 20.0	ug/L	EPA 8270D	2/21/14	W EEP	A	
Benzo(g,h,i)perylene	< 20.0	ug/L	EPA 8270D	2/21/14	W EEP	A	
Phenol	182	ug/L	EPA 8270D	2/21/14	W EEP	A	
2-Chlorophenol	< 100	ug/L	EPA 8270D	2/21/14	W EEP	A	
2-Methylphenol (o-cresol)	< 100	ug/L	EPA 8270D	2/21/14	W EEP	A	
3&4-Methylphenol (m&p-cresol)	2,420	ug/L	EPA 8270D	2/25/14	W EEP	A	
Cresols, Total	2,420	ug/L	EPA 8270D	2/25/14	W EEP	A	
2-Nitrophenol	< 200	ug/L	EPA 8270D	2/21/14	W EEP	A	
2,4-Dimethylphenol	< 100	ug/L	EPA 8270D	2/21/14	W EEP	A	
2,4-Dichlorophenol	< 100	ug/L	EPA 8270D	2/21/14	W EEP	A	
2,6-Dichlorophenol	< 100	ug/L	EPA 8270D	2/21/14	W EEP	N	
4-Chloro-3-methylphenol	< 200	ug/L	EPA 8270D	2/21/14	W EEP	A	
2,4,5-Trichlorophenol	< 200	ug/L	EPA 8270D	2/21/14	W EEP	A	
2,4,6-Trichlorophenol	< 200	ug/L	EPA 8270D	2/21/14	W EEP	A	
2,4-Dinitrophenol	< 400	ug/L	EPA 8270D	2/21/14	W EEP	A	
4-Nitrophenol	< 200	ug/L	EPA 8270D	2/21/14	W EEP	A	
4,6-Dinitro-2-methylphenol	< 400	ug/L	EPA 8270D	2/21/14	W EEP	A	
Pentachlorophenol	< 200	ug/L	EPA 8270D	2/21/14	W EEP	A	
BaP Toxic Equiv. Quotient	< 46.2	ug/L	EPA 8270D	2/21/14	W EEP	U	
B/N Surr.1 Nitrobenzene-d5	75	%	EPA 8270D	2/21/14	W EEP	N	
B/N Surr.2 2-Fluorobiphenyl	81	%	EPA 8270D	2/21/14	W EEP	N	
B/N Surr.3 Terphenyl-d14	95	%	EPA 8270D	2/21/14	W EEP	N	
Acid Surr.1 2-Fluorophenol	40	%	EPA 8270D	2/21/14	W EEP	N	
Acid Surr.2 Phenol-d8	29	%	EPA 8270D	2/21/14	W EEP	N	
Acid Surr.3 Tribromophenol	109	%	EPA 8270D	2/21/14	W EEP	N	
Unidentified Peaks	> 10		EPA 8270D	2/21/14	W EEP	U	

002 Site: Trip Blank — Date Sampled: 2/3/14 Time: 11:05

Parameter	Result	Units	Method	Analysis Date/Time	Lab/Tech	NELAC	Qual.
Volatile Organic Compounds							

ENDYNE Inc.
www.endynelabs.com

Table A-4: Concentration (µg/L) of Emerging Contaminants by Leachate Age (Andrews et al. 2012)

Compound	>25 Year Burial	3-16 Year Burial	<5 Year Burial
3-methyl-1h-indole	0.242	0.12*	<0.04
3-beta-coprostanol	<2	10.41*	13.41*
cholesterol	<2	9.42*	15.7*
beta-sistosterol	<2	17.7*	35.8*
4-t-octylphenol	1.24*	0.486*	0.463*
acetophenone	<0.649	0.516*	0.906*
benzophenone	<0.216	0.807*	1.07*
camphor	114*	1.55*	98.8*
d-limonene	0.245*	0.302*	<1.75
fluoranthene	<0.04	0.273*	<0.04
isoborneol	0.903	< 1.13	<5.26
cumene	0.945*	3.48*	2.06*
p-cresol	51.2*	35.2*	<0.18
tri(2-butoxyethyl) phosphate	2.43*	1.34*	2.54*
tri(dichloroisopropyl) phosphate	0.195	<0.12	<0.1
tributyl phosphate	2.25*	2.04*	1.83*
triphenyl phosphate	0.249	<0.12	<0.12
1-methylnapthalene	1.59	1.45*	0.728*
2,6-dimethylnapthalene	0.572	0.426*	<0.12
2-methylnapthalene	2.25	1.9*	1.02*
anthracene	0.271	0.286*	<0.04
naphthalene	9.53	9.91*	9.07*
phenanthrene	0.215	0.338*	<0.04
pyrene	<0.04	0.174*	<0.04
1,4-dichlorobenzene	2.11*	4.41*	24*
anthraquinone	0.26	0.271*	0.702*
carbaryl	0.942*	<0.61	<0.726
n,n-dimethyl-meta-toluamide (DEET)	52.6*	43.7*	52.8*

* = estimated concentration, detected below quantification limit

APPENDIX 3: 2015 biosolids management statistics

Table A-5: Vermont Biosolids Management Statistics for 2015

Management Option	In-State (wet tons)[1]	Out-of-State (wet tons)[1]	Total (wet tons)[1]	Percent of Total	Percent Managed
Beneficial Uses:					
Land Application	6,292	0	6,292	9.6%	
EQ Biosolids	9,646	17,098	26,744	40.7%	
Subtotal	15,938	17,098	33,036		50.3%
Non-Beneficial Uses:					
Landfill	31,919	0	31,919	48.6%	
Incineration[2]	0	721	721	1.1%	
Subtotal	31,919	721	32,640		49.7%
Total:	47,857	17,819	65,676	100%	100%
Total In & Out of State	72.9%	27.1%			

[1] All amounts of biosolids reported to DEC are converted to dry tons and converted to wet weight assuming 15% solids (dry tons x 0.15 = wet tons), which is generally the percent solids that can qualify to be landfilled.

[2] Please note that nearly all biosolids sent to incinerators are in liquid form and the actual weight is greater than that in this table.

APPENDIX 4: 2015 septage management statistics

Table A-6: Vermont Septage Management Statistics for 2015

Management Option	In-State (gallons)	Out-of-State (gallons)	Total (gallons)	Percent of Total	Percent Managed
Beneficial Uses:					
Land Application[1]	7,773,522	280,927	8,054,449	15.5%	
EQ Biosolids[2]	2,577,850	8,564,056	11,141,906	21.5%	
Subtotal	10,351,372	8,844,983	19,196,355		37.0%
Non-Beneficial Uses:					
Landfill[3]	28,522,561	898,532	29,421,093	56.8%	
Incineration	0	3,204,221	3.204,221	6.2%	
Subtotal	28,522,561	4,102,753	32,625,314		63.0%
Total:	38,873,933	12,947,736	51,821,669	100%	100%
Percent of Total In & Out of State	75.0%	25.0%			

[1] Septage that is directly land applied or disposed at a WWTF that land applies biosolids.

[2] Septage that is directly treated in an EQ process or disposed at a WWTF that produces EQ biosolids.

[3] Solids from dewatered septage that are disposed at a landfill or disposed at a WWTF that landfills biosolids.

APPENDIX 5: Radionuclides

Table A-7: Information Regarding Commonly Detected Radionuclides

Isotope	Half-life	Exposure Media	Source	Origin
Be-7	53.22 days	Groundwater	Natural	Cosmic radiation
Bi-214	19.9 months	Groundwater	Natural	Uranium decay
I-131	8.0 days	Medical	Manmade	Manufactured
K-40	1.25×10^9 years	Groundwater/soil	Natural	Primordial
Pb-212	10.6 hours	Soil	Natural	Thorium decay
Pb-214	26.8 months	Soil	Natural	Uranium decay
Ra-226	1600 years	Groundwater/soil/air	Natural	Uranium decay
Ra-228	5.75 years	Groundwater/soil/air	Natural	Uranium decay
Sr-89	50.5 days	Soil/air/medical	Manmade	Manufactured/nuclear weapons fallout
Th-228	1.91 years	Soil/groundwater	Natural	Thorium decay
Tl-201	73 hours	Medical	Manmade	Manufactured

APPENDIX 6: Dioxin/PCB toxicity factors

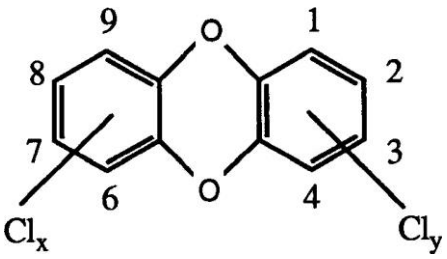
Table A-8: 2005 World Health Organization Toxic Equivalency Factors (TEFs)

CONGENER	WHO 2005 TEF
chlorinated dibenzo-p-dioxins	
2,3,7,8-TCDD	1.0
1,2,3,7,8-PeCDD	1.0
1,2,3,4,7,8-HxCDD	0.1
1,2,3,6,7,8-HxCDD	0.1
1,2,3,7,8,9-HxCDD	0.1
1,2,3,4,6,7,8-HpCDD	0.01
OCDD	0.0003
chlorinated dibenzofurans	
2,3,7,8-TCDF	0.1
1,2,3,7,8-PeCDF	0.03
2,3,4,7,8-PeCDF	0.3
1,2,3,4,7,8-HxCDF	0.1
1,2,3,6,7,8-HxCDF	0.1
1,2,3,7,8,9-HxCDF	0.1
2,3,4,6,7,8-HxCDF	0.1
1,2,3,4,6,7,8-HpCDF	0.01
1,2,3,6,7,8,9-HpCDF	0.01
OCDF	0.0003
non-ortho substituted PCBs	
3,3'4,4'-tetraCB (PCB77)	0.0001
3,4,4',5-tetraCB (PCB 81)	0.0003
3,3',4,4',5-pentaCB (PCB126)	0.1
3,3',4,4',5,5'-hexaCB (PCB169)	0.03
mono-ortho substituted PCBs	
2,3,3',4,4'-pentaCB (PCB 105)	0.00003
2,3,4,4',5-pentaCB (PCB 114)	0.00003
2,3',4,4',5-pentaCB (PCB 118)	0.00003
2',3,4,4',5-pentaCB (PCB 123)	0.00003
2,3,3',4,4',5-hexaCB (PCB 156)	0.00003
2,3,3',4,4',5'-hexaCB (PCB 157)	0.00003
2,3',4,4',5,5'-hexaCB (PCB 167)	0.00003
2,3,3',4,4',5,5'-heptaCB (PCB 189)	0.00003

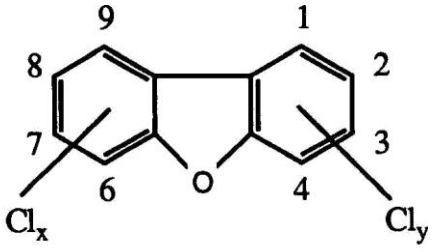
TEQ concentrations are calculated by multiplying the concentration of each PCDD/PCDF/PCB congener by its corresponding TEF and then summing the resulting numbers. TEQ concentrations are typically expressed as "parts per trillion TEQ".

T = tetra (4 Cl atoms at numbered positions)
Pe = penta (5 Cl atoms at numbered positions)
Hx = hexa (6 Cl atoms at numbered positions)
Hp = hepta (7 Cl atoms at numbered positions)
O = octa (8 Cl atoms at numbered positions)

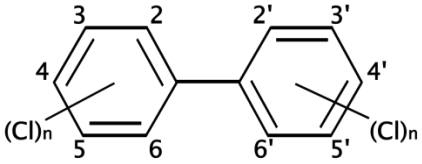
Dibenzo-p-dioxin molecule



Dibenzofuran molecule



Biphenyl molecule



APPENDIX 7: State biosolids contaminant limits

Table A-9: U.S. States Ceiling Concentrations for Land Applied Non-EQ Biosolids

STATE	NON-EQ BIOSOLIDS CEILING CONCENTRATIONS (Federal: 503.13 – Table 1)										
	As	Cd	Cr	Cu	Pb	Hg	Mo	Ni	Se	Zn	OTHER
503.13 – Table 1	75	85		4300	840	57	75	420	100	7500	
Alabama	75	85		4300	840	57	75	420	100	7500	
Alaska	***41***	***39***	***1200***	***1500***	***300***	***17***	75	420	100	***2800***	
Arizona	75	85	***3000***	4300	840	57	75	420	100	7500	
Arkansas	75	85		4300	840	57	75	420	100	7500	
California	75	85		4300	840	57	75	420	100	7500	
Colorado	75	85		4300	840	57	75	420	100	7500	
Connecticut	75	85		4300	840	57	75	420	100	7500	
Delaware	75	85	***3000***	4300	840	57	75	420	100	7500	
Florida	75	85		4300	840	57	75	420	100	7500	
Georgia	75	85		4300	840	57	75	420	100	7500	
Hawaii	***20***	***15***	***200***	***1500***	***300***	***10***	***15***	***100***	***25***	***2000***	
Idaho	75	85	***3000***	4300	840	57	75	420	100	7500	
Illinois [1]	75	85		4300	840	57	75	420	100	7500	
Indiana	75	85		4300	840	57	75	420	100	7500	
Iowa	75	85		4300	840	57	75	420	100	7500	
Kansas	75	85		4300	840	57	75	420	100	7500	
Kentucky	75	85		4300	840	57	75	420	100	7500	
Louisiana	75	85		4300	840	57	75	420	100	7500	***PCB: 10***
Maine [2]	***41***	***39***	***3000***	***1500***	***300***	***10***	75	420	100	***2800***	***TCDD/F [2]***
Maryland	75	85		4300	840	57	75	420	100	7500	***PCB: 10***
Massachusetts	75	85	***1000***	4300	840	57	75	420	100	7500	***PCB: 10***
Michigan	75	85		4300	840	57	75	420	100	7500	
Minnesota	75	85		4300	840	57	75	420	100	7500	
Mississippi	75	85		4300	840	57	75	420	100	7500	
Missouri	75	85	***3000***	4300	840	57	75	420	100	7500	
Montana	75	85		4300	840	57	75	420	100	7500	
Nebraska	75	85		4300	840	57	75	420	100	7500	
Nevada	75	85		4300	840	57	75	420	100	7500	
New Hampshire	***32***	***14***	***1000***	***1500***	***300***	***10***	***35***	***200***	***28***	***2500***	***PCB: 1*** ***TCDD/F [4]***
New Jersey	75	85		4300	840	57	75	420	100	7500	
New Mexico	75	85		4300	840	57	75	420	100	7500	
New York	***41***	***21***	***1000***	***1500***	***300***	***10***	***40***	***200***	100	***2500***	
North Carolina	75	85		4300	840	57	75	420	100	7500	
North Dakota	75	85		4300	840	57	75	420	100	7500	
Ohio	75	85		4300	840	57	75	420	100	7500	
Oklahoma	75	85		4300	840	57	75	420	100	7500	
Oregon	75	85		4300	840	57	75	420	100	7500	
Pennsylvania	75	85		4300	840	57	75	420	100	7500	***PCB: 8.6***
Rhode Island	75	85		4300	840	57	75	420	100	7500	
South Carolina	75	85		4300	840	57	75	420	100	7500	
South Dakota	75	85		4300	840	57	75	420	100	7500	
Tennessee	75	85		4300	840	57	75	420	100	7500	
Texas	75	85		4300	840	57	75	420	100	7500	
Utah	75	85		4300	840	57	75	420	100	7500	
Vermont	***15***	***21***	***1000***	***1500***	***300***	***10***	75	420	100	***2800***	***PCB: 10***
Virginia	75	85		4300	840	57	75	420	100	7500	
Washington	75	85		4300	840	57	75	420	100	7500	
West Virginia	75	85		4300	840	57	75	420	100	7500	
Wisconsin	75	85		4300	840	57	75	420	100	7500	
Wyoming	75	85		4300	840	57	75	420	100	7500	

Table A-10: U.S. States Concentration Limits for EQ Biosolids

STATE	EQ BIOSOLIDS CONCENTRATION LIMITS (Federal: 503.13 - Table 3)										
	As	Cd	Cr	Cu	Pb	Hg	Mo	Ni	Se	Zn	OTHER
503.13 – Table 3	41	39		1500	300	17		420	100	2800	
Alabama	41	39		1500	300	17		420	100	2800	
Alaska	41	39	***1200***	1500	300	17	***75***	420	100	2800	
Arizona	41	39	***3000***	1500	300	17	***75***	420	100	2800	
Arkansas	41	39		1500	300	17		420	100	2800	
California	41	39		1500	300	17		420	100	2800	
Colorado	41	39		1500	300	17		420	100	2800	
Connecticut	41	39		1500	300	17		420	100	2800	
Delaware	41	39	***1200***	1500	300	17	***18***	420	***36***	2800	
Florida	41	39		1500	300	17		420	100	2800	
Georgia	41	39		1500	300	17		420	100	2800	
Hawaii	***20***	***15***	***200***	1500	300	***10***	***15***	***100***	***25***	***2000***	
Idaho	41	39	***1200***	1500	300	17		420	100	2800	
Illinois [1]	41	39		1500	300	17		420	100	2800	
Indiana	41	39		1500	300	17	***75***	420	100	2800	
Iowa	41	39		1500	300	17		420	100	2800	
Kansas	41	39		1500	300	17	***75***	420	100	2800	
Kentucky	41	39		1500	300	17	***75***	420	100	2800	
Louisiana	41	39		1500	300	17		420	100	2800	***PCB: 10***
Maine	41	39	***3000***	1500	300	***10***	***75***	420	100	2800	***TCDD/F [2]***
Maryland	41	39		1500	300	17		420	100	2800	
Massachusetts	41	***14***	***1000***	***1000***	300	***10***	***25***	***200***	100	***2500***	***Boron: 300*** ***PCB: 2***
Michigan	41	39		1500	300	17	***75***	420	100	2800	
Minnesota	41	39		1500	300	17	***75***	420	100	2800	
Mississippi [3]	41	39		1500	300	17	***18***	420	***36***	2800	
Missouri	41	39	***1200***	1500	300	17		420	100	2800	
Montana	41	39		1500	300	17		420	100	2800	
Nebraska	41	39		1500	300	17		420	100	2800	
Nevada	41	39		1500	300	17		420	100	2800	
New Hampshire	***10***	***10***	***160***	***1000***	***270***	***7***	***18***	***98***	***18***	***1780***	***PCB: 1*** ***TCDD/F [4]***
New Jersey	41	39		1500	300	17	***75***	420	100	2800	
New Mexico	41	39		1500	300	17		420	100	2800	
New York	41	***10***	***1000***	1500	300	***10***	***40***	***200***	100	***2500***	
North Carolina	41	39		1500	300	17		420	100	2800	
North Dakota	41	39		1500	300	17		420	100	2800	
Ohio	41	39		1500	300	17		420	100	2800	
Oklahoma	41	39		1500	300	17		420	100	2800	
Oregon	41	39		1500	300	17		420	100	2800	
Pennsylvania	41	39		1500	300	17		420	100	2800	***PCB: 4***
Rhode Island	41	39		1500	300	17		420	100	2800	
South Carolina	41	39		1500	300	17		420	100	2800	
South Dakota	41	39		1500	300	17		420	100	2800	
Tennessee	41	39		1500	300	17		420	100	2800	
Texas	41	39		1500	300	17		420	100	2800	
Utah	41	39		1500	300	17		420	100	2800	
Vermont	***15***	***21***	***1000***	1500	300	***10***	***75***	420	100	2800	***PCB: 10***
Virginia	41	39		1500	300	17		420	100	2800	
Washington	41	39		1500	300	17		420	100	2800	
West Virginia	41	39		1500	300	17		420	100	2800	
Wisconsin	41	39		1500	300	17		420	100	2800	
Wyoming	41	39		1500	300	17		420	100	2800	

FOOTNOTES: Tables A-9 and A-10

all standards are in units of (mg/kg, dry wt.) unless otherwise noted in a footnote below.
blank cells = no standard established under Part 503 or by the State.
normal font = State standard the same as 503.13 Table 1 or Table 3.
bold italic font = State standard different than or in addition to 503.13 Table 1 or Table 3.

[1] Illinois:

Employs the 503 limits as screening standards, but regulates based on site specific APLR and CPLR limits.

[2] Maine:

Standards are based on monthly average concentrations.
Maine also employs screening standards for Non-EQ biosolids (lower than the ceiling concentration limits) which if exceeded mandate the implementation of additional land application site management practices.

TCDD/F: <27 ppt TEQ - no restrictions, 27 - 250 ppt TEQ – additional management practices and site title recording requirements apply, >250 ppt TEQ – prohibited.

[3] Mississippi:

For EQ, biosolids must first meet the standards cited in Table A-8. Secondly, if the biosolids exceed any of the following contaminant concentrations (mg/kg, dry wt.): As: 10, Ba: 200, Cd: 2, Cr: 10, Pb: 10, Hg: 0.4, Se: 2, Ag: 10 - the biosolids must be subjected to and pass a TCLP analysis for the contaminant(s) exceeded.

[4] New Hampshire:

10 ppt TEQ for 2,3,7,8 TCDD and 2,3,7,8 TCDF individually, 27 ppt TEQ total for all congeners of TCDD and TCDF with an assigned TEF.

APPENDIX 8: International biosolids contaminant limits

Table A-9: Regulatory Limits for Agricultural Use in Selected Nations and Provinces

COUNTRY/PROVINCE	REGULATORY LIMIT FOR AGRICULTURAL USE (mg/kg, dry wt.)											
	As	Ba	Cd	Co	Cr	Cu	Pb	Hg	Mo	Ni	Se	Zn
Australia (Class 1)	20		3		100	100	150	1		60	3	200
Australia (Class 2)	60		20		500	2500	420	15		270	50	2500
Brazil	41	1300	39		1000	1500	300	17	50		100	2800
Bulgaria	30		30		500	1500	1000	16		300		3000
Canada - British Colombia	75		20	150	1060	2200	500	5	20	180	14	1850
Canada - New Brunswick			20			888	56	3.1	7.6	26.4	4.2	588
Canada - Ontario	170		34	340	2800	1700	1100	11		420		4200
Canada - Quebec (Class 1)	13		3	34	210	400	150	0.8	5	62	2	700
Canada - Quebec (Class 2)	40		10	150	1060	1000	300	4	20	180	14	1850
Canada - Saskatchewan	75		20	150	1060	760	500	5	20	180	14	1850
Canada (Class A)	13		3	34	210	400	150	0.8	5	62	2	700
China	75	150	5		600	800	300	5		100		2000
Czech Republic	30		5		200	500	200	4		100		2500
Finland	25		1.5		300	600	100	1		100		1500
Germany			10		900	800	900	8		200		2500
Hungary	75		10	50	1000	1000	750	10	20	200	100	2500
Italy			20			1000	750	10		300		2500
Japan	50		5		500		100	2		300		
Jordan (Type 1)	41		40		900	1500	300	17	75	300	100	1800
Jordan (Type 2)	75		40		900	3000	840	57	75	400	100	4000
Jordan (Type 3)	75		85		3000	4300	840	57	75	420	100	7500
Mexico	41		39		1200	1500	300	17		420		2800
Netherlands	15		1.25		75	75	100	0.75		30		300
New Zealand (Grade A)	20		3		600	100	300	1		60		300
New Zealand (Grade B)	30		10		1500	1250	300	7.5		135		1500
Norway			2		100	650	80	3		50		800
Russia	10		15		500	750	250	7.5		200		1750
Slovakia	20		10		1000	1000	750	10		300		2500
Slovenia	20		0.5		40	30	40	0.2		30		100
South Africa (Class A)	40		40		1200	1500	300	15		420		2800
Switzerland			5	60	500	600	500	5	20	80		2000
Turkey			40		1200	1750	1200	25		400		4000
Vermont	15		21		1200	1500	300	10	75	420	100	2800

blank cells = no regulatory standard adopted

Source: U.N. - Human Settlements Programme and Greater Moncton Sewerage Commission (2008). "Global Atlas of Excretia, Wastewater Sludge, and Biosolids Management: Moving Forward the Sustainable and Welcome Uses of a Global Resource".

APPENDIX 9: Acronyms

Acronym	Definition
ADI	Acceptable Daily Intake
ANR	Vermont Agency of Natural Resources
ANSI	American National Standards Institute
APLR	Annual Pollutant Loading Rate
BOD	Biochemical Oxygen Demand
CDC	Centers for Disease Control
CEC	Contaminants of Emerging Concern
CFR	Code of Federal Regulations
CPLR	Cumulative Pollutant Loading Rate
CSWD	Chittenden Solid Waste District
CWA	Clean Water Act
DAFM	Vermont Department of Agriculture, Food & Markets (now VAAFM)
DEC	Vermont Department of Environmental Conservation
EDC	Endocrine Disrupting Compound
EQ	Exceptional Quality (biosolids)
FTE	Full Time Equivalents
ISCORS	Interagency Steering Committee on Radiation Standards
MDL	Method Detection Limit
NEBRA	North East Biosolids and Residuals Association
NOAEL	No Observable Adverse Effect Level
NPDES	National Pollutant Discharge Elimination System
NRC	National Research Council
NSF	National Sanitation Foundation (now NSF International)
OECA	EPA's Office of Enforcement and Compliance Assistance
PAH	Polyaromatic Hydrocarbon
PBDE	Polybrominated Diphenyl Ether (flame retardants)
PCB	Polychlorinated Biphenyl
PCDD/PCDF	Polychlorinated Dibenzodioxin/dibenzofuran (dioxins)
PEC	EPA's Pathogen Equivalency Committee
PFOA	Perfluorooctanoic acid
PFOS	Perfluorooctane sulfonic acid
PFRP	Process to Further Reduce Pathogens
PPCP	Pharmaceutical and Personal Care Products
PSRP	Process to Significantly Reduce Pathogens
RfD	Risk Reference Dose
TCLP	Toxicity Characteristic Leaching Procedure
TEF	Toxic Equivalency Factor
TEQ	Toxic Equivalents
TMDL	Total Maximum Daily Load
TNSSS	Targeted National Sewage Sludge Survey
USDA	United States Department of Agriculture
USEPA (EPA)	United States Environmental Protection Agency
VAAFM	Vermont Agency of Agriculture, Food & Markets
VAR	Vector Attraction Reduction
VDOH	Vermont Department of Health
VSWMR	Vermont Solid Waste Management Rules
WEP	Water Extractable Phosphorus
WERF	Water Environment Research Foundation
WWTF	Wastewater Treatment Facility